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Petrology and structure Bayonne batholith southeastern British Columbia

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PETROLOGY AND STRUCTURE, BAYONNE BATHOLITH, SOUTHEASTERN BRITISH COLUMBIA

by

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ABSTRACT

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The primary purpose of this study is to determine if a major fault lies buried in the Purcell Trench near the southern end of Kootenay Lake in southeastern British Columbia and how such a fault might be related to the structural evolution of the Selkirk metamorphic core complex (SMCC) to the south.

Petrographic data indicates the existence in the Bayonne batholith of two previously unrecognized granitic phases, one an S-type granite. S- and I-type plutons in the region may have been emplaced during separate intrusive events. The most westerly and north-westerly occurrences of S-type granites in the region broadly coincide with the location of the Kootenay Arc, and this boundary may mark the western edge of autochthonous Precambrian continental crust.

A roughly north-south-trending zone of ductile and cataclastic deformation has developed in rocks of the Bayonne batholith. Three stages of deformation history, possibly representing two separate tectonic events, can be distinguished. Later ductile deformation produced conjugate east- and west-dipping mylonite shears for which a normal sense of displacement is indicated. The conjugate shears indicate a subhorizontal, ENE-WSW extension. Later ductile and cataclastic structures could have been produced by stresses of the same orientation during a single tectonic event.

Stratigraphic offsets and contrasts in metamorphic grade and late thermal histories of intrusive rocks across the Purcell Trench near the southern end of Kootenay Lake suggest a major fault buried in the trench. The structures exposed near Kootenay Landing may be subsidiary to the postulated Purcell Trench fault. The presence of the features suggesting the postulated Purcell Trench fault and a slickenside lineation parallel to one measured 65 km to the south expand to the north the range of the terrane that can be considered the SMCC. The second tectonic event of this study correlates at least with the later cataclastic deformation event of the SMCC and other core complexes and is interpreted to have occurred during the Eocene.

ACKNOWLEDGMENTS

I would like to dedicate this thesis to my wife, Karen, who nurtured it and me in many ways over the years and drafted most of the figures.

I sincerely appreciate the unwavering support that my committee members, Dave Fountain, Don Hyndman and Rob Ream, have given me throughout the evolution of the study.

Finally, I want to thank Doug Archibald, Fred Miller and Ray Price for graciously sharing their knowledge with me.

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CHAPTER I

INTRODUCTION

The high-grade metamorphic/plutonic terrane of the Selkirk mountains of northern Idaho and northeastern Washington displays many of the characteristics of metamorphic core complexes elsewhere in the western North American Cordillera (Coney, 1980). The Purcell Trench, a north-south-trending topographic feature, separates the high-grade metamorphic terrane of the Selkirk mountains on the west from a low-grade metamorphic terrane on the east, and several geologists have postulated major faults buried in the trench (e.g. Miller and Engels, 1975). The continuation of the postulated Purcell Trench fault north from the US-Canada border is problematic. The primary purpose of this thesis is to determine if a major fault might be buried in the Purcell Trench in the vicinity of the southern end of Kootenay Lake, 30 kilometers north of the US-Canada border (see Fig. 1). If such a fault does exist, it should be determined what type of fault it might be, when it might have been active and how it might relate to the Selkirk metamorphic core complex identified to the south.

In this study I mapped several geologic features in order to address the tectonic questions. The Bayonne batholith is exposed on both sides of the Purcell Trench in the study area, and I mapped various distinctive phases of the batholith to determine if the phases might be in fault contact. A zone of ductile and cataclastic deformation exposed

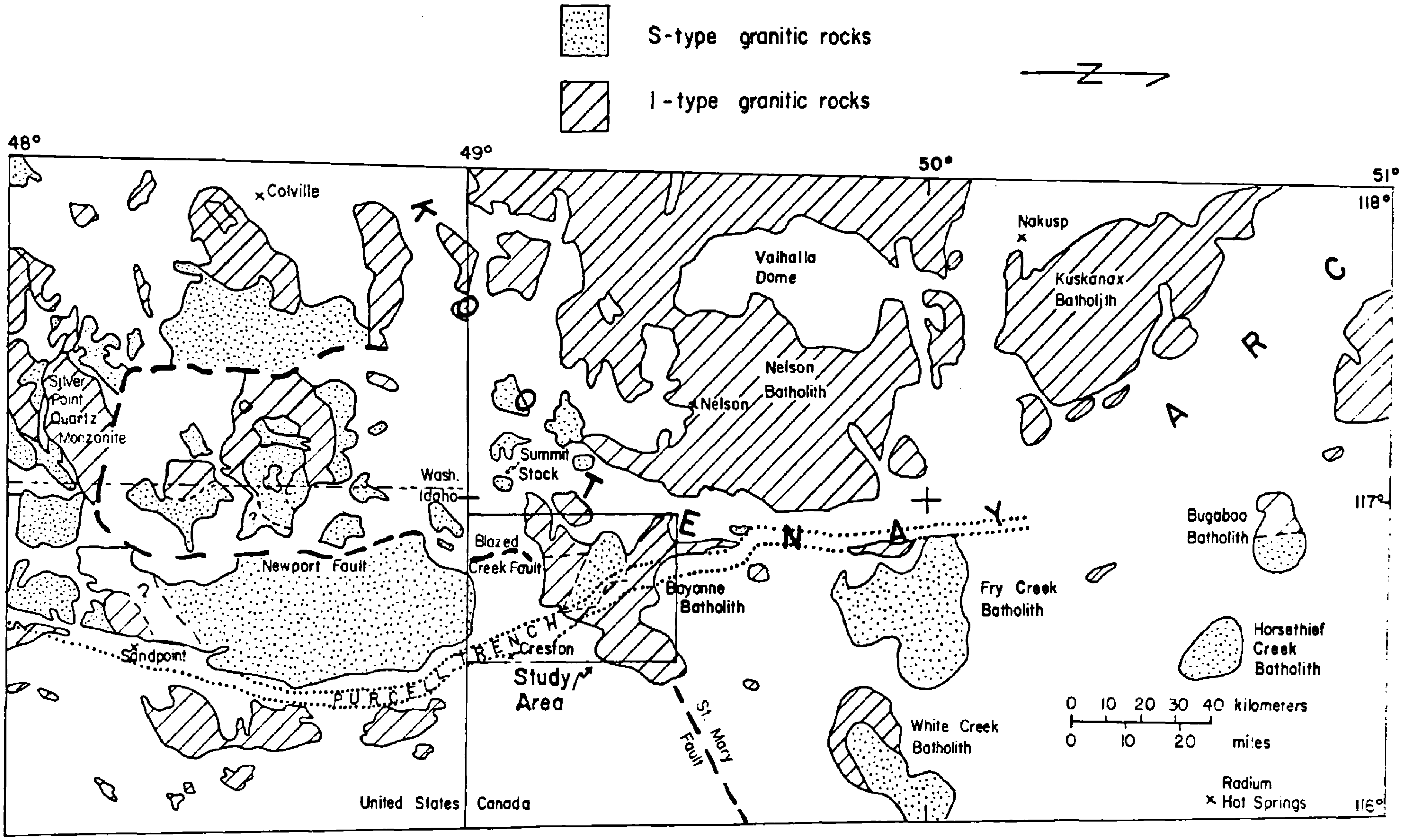


Figure 1. Plutonic rocks and major structures of the Selkirk-Priest River region. Modified from Rice (1941), Little (1960), Wheeler (1965), Hyndman (1968b), Reesor (1958, 1973 and 1976), Miller and Engels (1975) and GSC map 1505A (1981).

near Kootenay Landing at the southern end of Kootenay Lake on the west side of the Purcell Trench was mapped and structures in that zone were analyzed. The results of this mapping are shown in Figure 2 as modifications of geologic mapping by other workers in the area.

Location and Access

The field area lies on both sides of the Kootenay River-Kootenay Lake valley north of Cretson, B.C. (see Fig. 1). Field work was mainly concentrated along the valley floor and included forays up several roaded side canyons. Rock exposures are quite good in railroad cuts, along the shoreline of the lakes, in highway and logging road cuts and locally on high ridges, but most of the field area is covered by dense vegetation and a thick accumulation of glacial debris.

Data on the east side of the area comes from road cuts along Highway 3A. The west side of the area is reached by walking two miles across the Canadian Pacific Railway causeway-bridge system from Highway 3A near Sirdar. At much higher elevations, access is by a private logging road starting from Highway 3 in Summit Creek and paralleling the Kootenay valley and by logging road up Blazed Creek. A road drops down to Kootenay Lake in Cultus Creek a few miles north of the area, but because the connecting road shown on recent maps between Blazed Creek and Cultus Creek no longer exists, one must approach that access from the Salmo, B.C. side.

Structural Setting

Projections of three regional structural features - the Kootenay Arc,

Figure 2. Geologic map. Modified from Rice (1941), Glover (1978) and Leclair (1982).

Kk Kootenay Landing Granite (Cretaceous)

Kb Main mass of the Bayonne batholith (Cretaceous)

Jm Mine and Wall stocks (Jurassic)

gn Orthogneiss of uncertain age

p€w Windermere Supergroup (Proterozoic)

p€p Purcell (Belt) Supergroup (Proterozoic)

Deformation zone

Sedimentary contact; solid where indicated, dashed where postulated

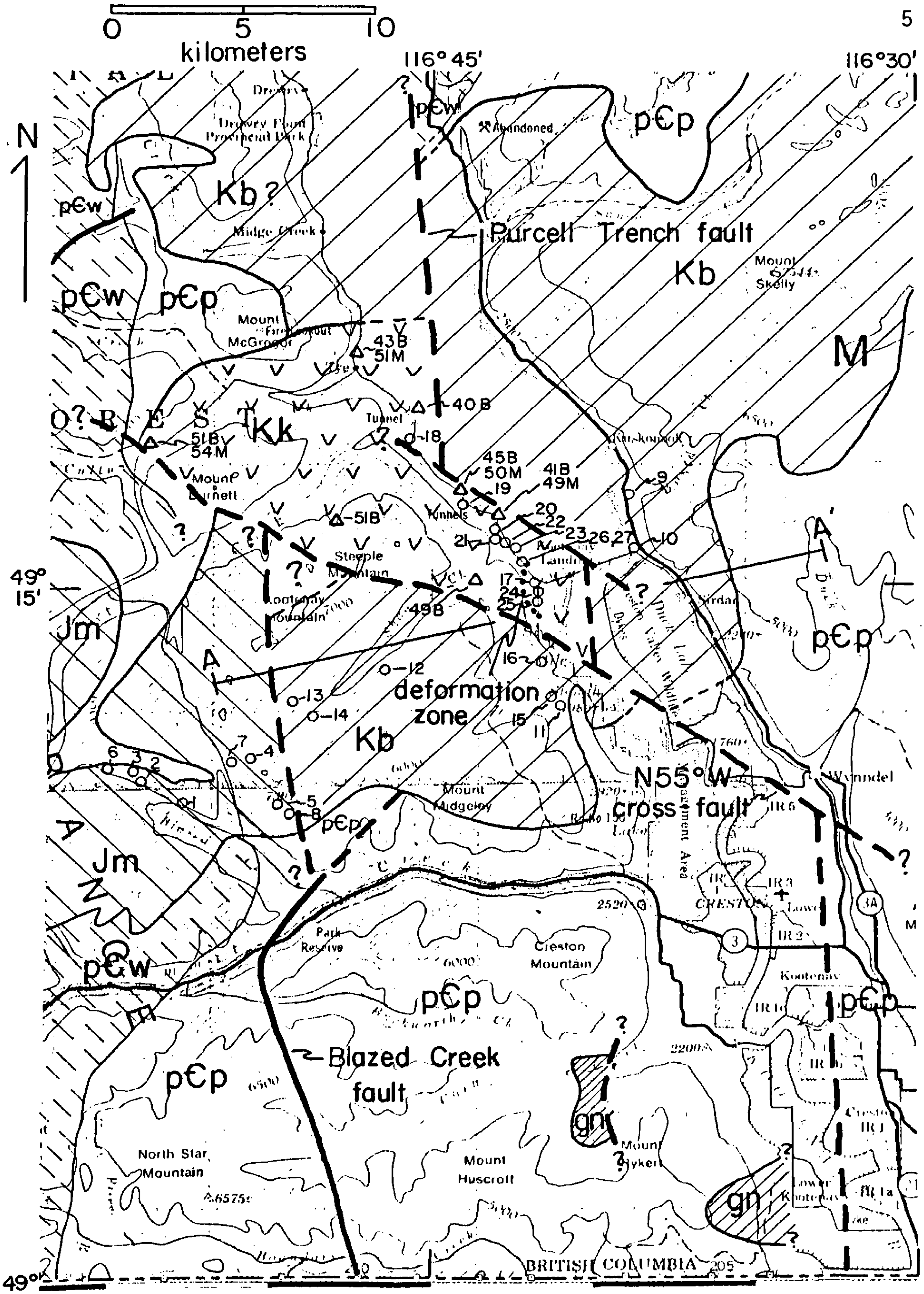
Intrusive contact; solid where indicated, dashed where postulated

Fault contact; solid where indicated, dashed where postulated

17 Petrologic sample location

43B 51M K-Ar sample location and data; B = biotite, M = muscovite (D. Archibald, personal comm., 1981)

A A' Location of cross-section (Figure 20)



0 5 10
kilometers
N
116°45'
116°30'
49° 15'
49°
pЄw
pЄp
Kb?
Kb
M
Kk
Jm
gn
Purcell Trench fault
deformation zone
N55°W cross fault
Blazed Creek fault
A
A'
Mount McGregor
Mount Skelly
Mount Lunnett
Steeple Mountain
Kootenay Mountain
Mount Midgeley
Creston Mountain
North Star Mountain
Mount Huscroft
Mount Ryker
Midge Creek
Kuskonook
Sirdar
Wynndel
CRESTON
Tunnel
Tunnels
Abandoned
Park Reserve
BRITISH COLUMBIA

the St. Mary fault and the eastern edge of the Selkirk metamorphic core complex delineated by the Purcell Trench - converge in the vicinity of the southern end of Kootenay Lake. These structures are located on Figure 1 and their salient characteristics are outlined below.

Kootenay Arc. The Kootenay Arc is a broad arcuate belt of highly deformed late Precambrian, Paleozoic and Mesozoic metasedimentary and metavolcanic rocks. For much of its length in Canada the Kootenay Arc separates the high-grade, polydeformed metamorphic terrane of the Shuswap metamorphic complex on the west from the Purcell anticlinorium and the imbricate thrust terrane of the Purcell and Rocky Mountains to the east. The Kootenay Arc is characterized by high, penetrative strains and complex tectonic overprinting associated with greenschist and amphibolite facies regional metamorphism and coaxial refolding about north- and northwest-trending axes (Fyles, 1967; Price, 1980). In spite of its complex internal structure, the Kootenay Arc can be interpreted as a simple westerly facing monocline of crustal dimensions (Price, 1980). Based on geophysical evidence and balanced structure sections, Price (1980) concludes that the present position of the Kootenay Arc marks the western edge of the Precambrian continental crust that forms the basement of the North American craton.

St. Mary fault. The St. Mary fault lies northeast of the Bayonne batholith and is a northwest-dipping, right-hand reverse structure related to foreland thrusting (Lis and Price, 1976). The St. Mary fault follows the locus of late Proterozoic fault displacements separating an uplifted source area to the southeast from a deep structural basin to the northwest (Lis and Price, 1976). Stratigraphic contrasts throughout the Proterozoic and early Paleozoic systems across the trend of the fault had a profound effect on foreland thrusting to the east (Benvenuto and Price, 1979).

Rice (1941) suggested that the Blazed Creek fault, a northeast-trending fault on the southwest edge of the Bayonne batholith, might be a continuation of the St. Mary fault. Stratigraphic similarities between the area southwest of the Bayonne batholith and the area along the St. Mary fault to the northeast corraborate Rice's (1941) interpretation (Glover, 1978).

The St. Mary fault lies along the trend of a major crustal structure identified geophysically by Kanasewich and others (1969), and the fault may be localized by that crustal weakness. In southeastern British Columbia this trend marks a dramatic change in Bouguer anomaly patterns (Stacey, 1973; D. Fountain, personal comm., 1982). The significance of this geophysical anomaly is unknown.

The trend of the Kootenay Arc changes from about north-south to about northeast-southwest in the vicinity of the southern end of Kootenay Lake. The northeast-trending portion of the Kootenay Arc lies, in a broad sense, along the southwesterly projection of the major crustal structure defined by Kanasewich and others (1969).

Selkirk metamorphic core complex. The Selkirk metamorphic core complex is a high-grade metamorphic/plutonic terrane centered in the Selkirk Mountains of northern Idaho and northeastern Washington (Coney, 1980). This complex includes the possibly pre-Beltian high-grade metamorphic rocks of the Spokane dome (Cheney, 1980).

The Selkirk metamorphic core complex is characterized by voluminous granitic plutons of both two-mica and hornblende-biotite suites, amphibolite-facies regional metamorphic rocks and the widespread occurrence of discordant Eocene radiometric ages (Miller and Engels, 1975). Mylonite and cataclastite are abundant in the complex, especially in association with the broadly synformal Newport fault which separates the high-grade metamorphic terrane from an overlying low-grade metamorphic terrane. Plutonic rocks above the Newport fault have not experienced the Eocene late cooling or reset event but rather yield Cretaceous radiometric dates. Structures apparently analogous to the Newport fault cut across older Kootenay Arc structures elsewhere in the region (Price, 1981).

The Purcell Trench bounding the Selkirk metamorphic core complex on the east is a north-south-trending topographic feature extending from Coeur d'Alene, Idaho to the Rocky Mountain Trench in British Columbia. The Purcell Trench might conceal major faults (Griggs, 1964; Miller and Engels, 1975). The nature of the structures possibly concealed in the trench remains enigmatic, however, because the trench is covered by lakes or glacial deposits for most of its length. The following evidence suggests the existence of a major fault buried in the Purcell Trench (Miller and Engels, 1975):

1) only two-mica plutons are exposed between the trench and the Newport fault, whereas only hornblende-biotite plutons crop out east of the trench,
2) the metamorphic grade changes markedly across the trench,

from amphibolite-facies on the west to almost no signs of metamorphism on the east,

3) the edge of a zone of radiometric age discordance coincides with the trench,

4) the form of radiometric age contours is distinctly different across the trench,

5) mylonite and cataclasite are extensively developed within and along the west side of the trench, and

6) landforms indicate that the west side of the trench may be a fault scarp.

This evidence is compatible with major displacement on a strike-slip or thrust fault (Miller and Engels, 1975), a low-angle listric normal or detachment-type fault, or some combination of the above.

CHAPTER 2

IGNEOUS PETROLOGY

Petrology of the Bayonne Batholith

General features. The Bayonne batholith lies on both sides of the Purcell Trench at the southern end of Kootenay Lake (Daly, 1912). Geologic mapping on the west side of the trench indicated the existence of distinctive granitic phases whose contacts were not shown on geologic maps. Petrographic data suggest criteria for distinguishing amongst the various granitic phases.

The name Bayonne batholith as applied to all apparently contiguous granitic rocks at the southern end of Kootenay Lake is retained in this study, but the composite nature of the batholith, both in terms of composition and probable age, is emphasized.

Estimated modes of granitic rocks from 26 localities in the Bayonne batholith are shown in Table 1. All mineral species were determined optically. Rock types are identified according to the IUGS classification (Streckeisen, 1976). These data are plotted on a QAP diagram in Figure 3. Sample localities are plotted on Figure 2.

Mine stock. Rice (1941) and Archibald and others (1977) demonstrated that the Mine stock forming the western portion of the Bayonne batholith is an older granitic body than the main mass of the batholith. My investigation showed that the Mine stock itself consists of at least two phases, the previously identified hornblende-biotite-bearing

	Mine stock								main mass								Kootenay Landing Granite									
	hb-bi-brg.					bi-brg.																				
Sample number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Quartz	25	25	19	17	10	32	20	30	25	40	26	23	35	24	15	13	35	30	40	40	40	20	39	50	50	45
Plagioclase	33	42	35	45	55	45	45	34	54	23	50	50	40	40	49	56	25	13	35	28	29	10	35	18	13	28
Orthoclase		2	7				2	1			2	1	15	20	20	1										
Microcline	9	1	8			3			2	21						1	35	40	20	25	25	61	10	25	30	22
Biotite	15	25	17	15	15	17	20	20	11	13	20	18	10	15	15	23	3	7	4	6	5	4	15	5	5	4
*pleochroism	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	R	R	R	R	R	R	R	R	R	R
Hornblende	10	3	5	11	13				1	1	tr	1	tr	x	tr	tr										
Epidote	8	5	9	12	7	2	13	15	7	1	2	5		1	1	3										
Muscovite																	2	10	1	1	1	5	1	2	2	1
Sphene		x	x	x	tr	x	x	x	x	x	x	tr	tr	x	tr	1										
Apatite	x	x	x	x	x	x	x	x	x	x	x	tr	x	x	x	tr	x	x	x	x	x	x	x	x	x	x
Zircon	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Magnetite	x	x	x	x					tr	1	tr	1	tr	tr	tr	2										
Garnet	x	x	x	x							x		x	x	x		tr		x	x	x		tr	x		x
Ilmenite																x	x				tr	x	x	x	x	x
Rutile											x	x														
Calcite		x		x			x																			

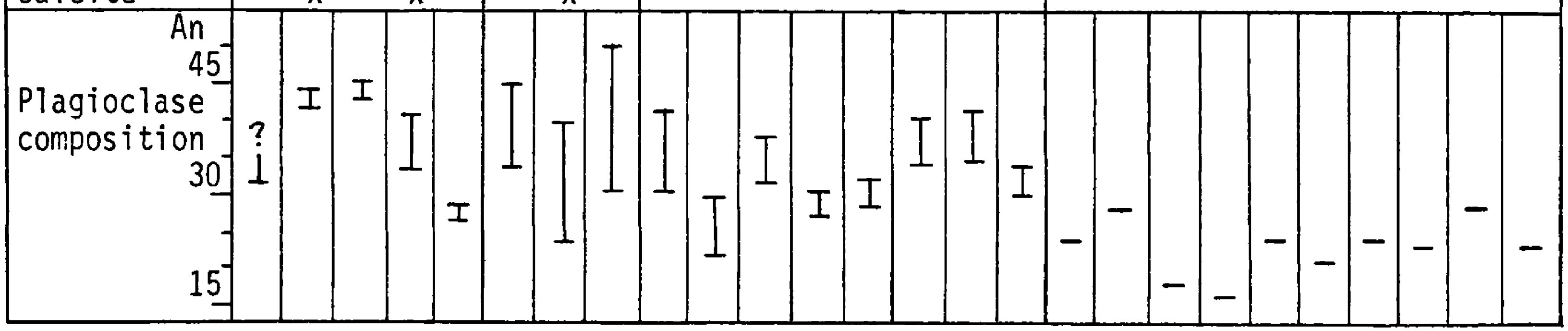
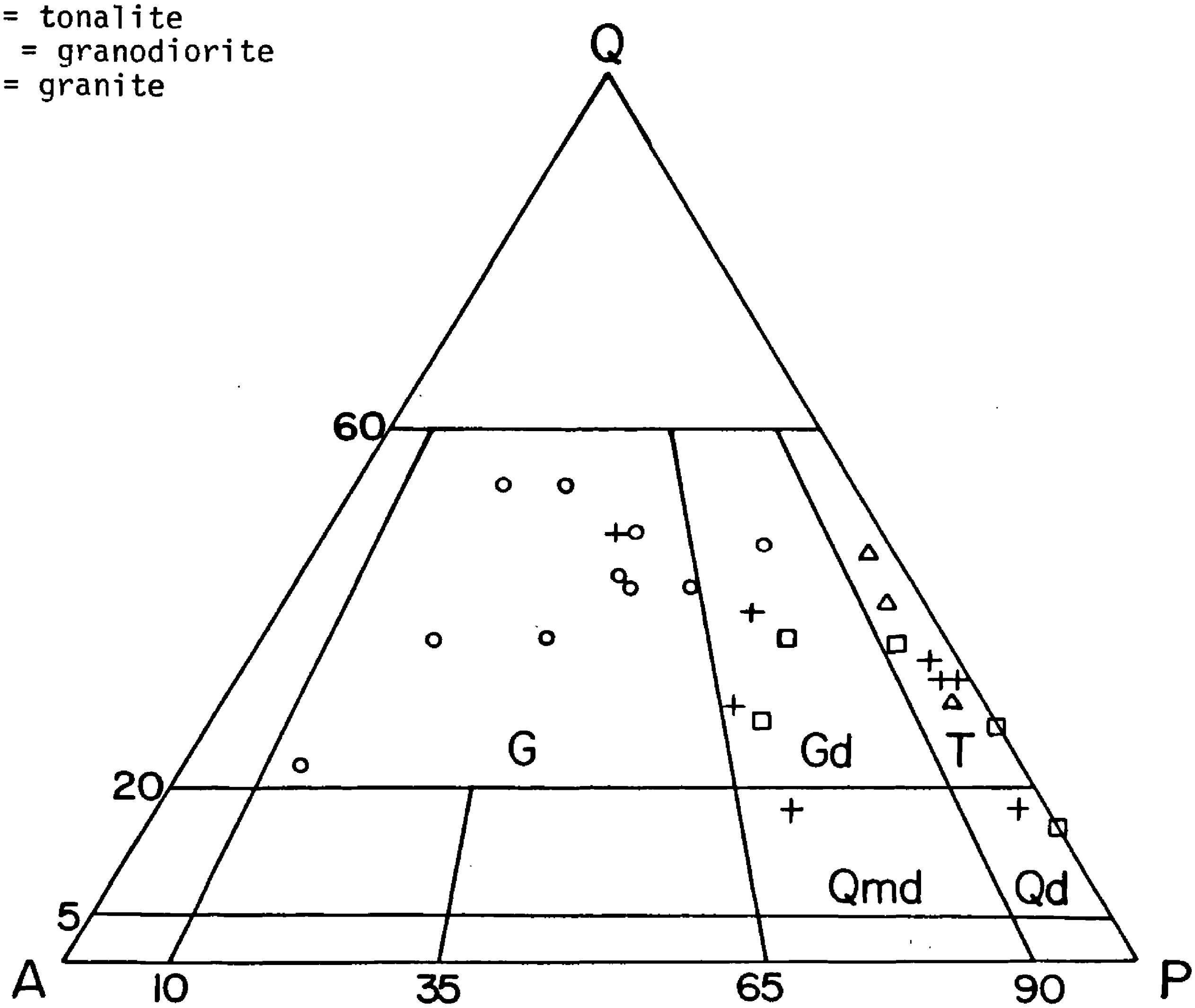


Table 1. Estimated modes of 26 samples from the Bayonne batholith. All mineral species determined optically. 1-5 Mine stock, hornblende-biotite-bearing phase; 6-8 Mine stock, biotite-bearing phase; 9-16 main mass of the Bayonne batholith; 17-26 Kootenay Landing Granite. * G = greenish-brown, R = reddish-brown; tr less than 1.0 but greater than 0.5 per cent; x less than 0.5 per cent.

Qmd = quartz monzodiorite
Qd = quartz diorite
T = tonalite
Gd = granodiorite
G = granite



o = Kootenay Landing Granite

\+ = main mass of the Bayonne batholith

□ = Mine stock, hornblende-biotite-bearing phase

△ = Mine stock, biotite-bearing phase

Figure 3. QAP plot of estimated modes of 26 samples from the Bayonne batholith. Rock types identified according to the IUGS classification (Streckeisen, 1976).

phase and a newly identified biotite-bearing phase.

Both phases of the Mine stock contain greenish-brown biotite as the dominant mafic mineral. Subhedral plagioclase shows normal zoning and simple and multiple twinning. Andedral potassium feldspar is both microcline and orthoclase, has simple and tartan twinning and is commonly microperthitic. Quartz commonly shows undulose extinction. Medium-grained secondary epidote is conspicuous. Accessory minerals include apatite, zircon, garnet, sphene and carbonate. Both phases contain numerous narrow pegmatite dikes.

The hornblende-biotite-bearing phase most characteristic of the Main and Wall stocks contains appreciable quantities of hornblende (Rice, 1941). Hornblende and biotite together constitute about twenty-five percent of the rock. This rock is generally fine- to medium-grained, non-porphyritic and locally weakly foliated. Rock types represented in five samples include granodiorite, tonalite and quartz diorite. The average plagioclase composition ranges from An_{39} in the cores of grains to An_{35} in the rims. Numerous inclusions, many of them carbonate-rich, occur in the hornblende-biotite-bearing phase of the Mine stock on the ridge east of Jersey Creek. One inclusion exposes an estimated 50 meters of stratigraphic section high in a cirque wall. In this vicinity the granitic rocks lack potassium feldspar and contain accessory carbonate, possibly as a result of contamination of the magma by assimilation of metasedimentary rocks.

The newly identified biotite-bearing phase of the Mine stock lacks even trace amounts of hornblende, the biotite constituting about nineteen percent of the rock. This phase is medium-grained and porphyritic, with phenocrysts of quartz. Three samples of this phase are tonalites. The average plagioclase composition ranges from An_{45} in the cores of grains to An_{29} in the rims. Alteration of plagioclase to sericite and of biotite to chlorite is common. Accessory pyrite occurs in some of these altered rocks.

Accessory magnetite was not noted in any of the samples of the biotite-bearing phase of the Mine stock. A weak aeromagnetic high trending about east-west in the vicinity of Blazed Creek (GSC map 8475G) may mark the outcrop of the hornblende-biotite-bearing phase of the Mine stock, which does contain some magnetite.

The contact relationship between the Mine stock and the main mass of the Bayonne batholith is unknown. The contact may be exposed along the ridge line separating the headwaters of Shaw Creek and Toby Creek.

Main mass of the Bayonne batholith. As noted by Rice (1941), the main mass of the Bayonne batholith contains minor amounts of hornblende, but greenish-brown biotite is by far the dominant mafic mineral, constituting about fifteen percent of the rock. This phase is typically medium-grained and porphyritic, with phenocrysts of plagioclase, potassium feldspar and quartz. Rock types represented in eight samples include granite, granodiorite, tonalite, quartz diorite and quartz monzodiorite. Garnet-bearing pegmatites are common. Medium-grained secondary epidote is common and fine-grained muscovite is rare. Plagioclase shows normal zoning, the average composition ranging from An_{35} in the cores of grains to An_{38} in the rims. Plagioclase is generally subhedral and has both simple and multiple twinning. Anhedral potassium feldspar is both microcline and orthoclase and has simple and tartan twinning. Potassium feldspar is commonly microperthitic. The potassium feldspar to plagioclase ratio averages 0.22. Quartz commonly shows undulose extinction and, locally, kink bands. Accessory minerals include magnetite, sphene, apatite, zircon, garnet and rutile. The partial alteration of plagioclase to sericite and of biotite to chlorite is widespread.

Granitic rocks exposed in highway cuts on the east side of Kootenay Lake are in most respects identical to rocks of the main mass of the Bayonne batholith exposed on the west side of the lake. On the east side, rocks typically are more altered, secondary chlorite and sericite being more common. The distinctive textural heterogeneity and presence of numerous xenoliths and inclusions noted by Rice (1941) are more evident on the east side.

The following characteristics of the main mass of the Bayonne batholith should generally serve to distinguish it from those rocks of the Mine stock that lack hornblende:

1) the presence of feldspar phenocrysts,
2) the less calcic plagioclase with a more limited range of An content between the core and the rim,
3) the presence of at least trace amounts of hornblende,
4) the lower epidote content, and
5) the higher magnetite and sphene contents.

<u>Kootenay landing granite</u>. Muscovite-biotite granite is exposed for at least 12 kilometers along the west shore of Kootenay Lake at its southern end. This pluton is here named the Kootenay Landing Granite after the former lake-streamer terminal. A new name is given to this phase because it is compositionally distinct from other phases of the Bayonne batholith and easily distinguished in the field.

The Kootenay Landing Granite is fine- to medium-grained, commonly flow(?)-foliated and locally compositionally variable. It is generally non-porphyritic, but the finer-grained phases are locally weakly porphyritic with plagioclase phenocrysts. Pegmatite dikes are abundant. Plagioclase is unzoned, and its composition averages about An_{22}. Plagioclase crystals are euhedral to subhedral and show both simple and multiple twinning. Subhedral to anhedral microcline, the only potassium feldspar, shows simple and tartan twinning and is microperthitic. The potassium feldspar to plagioclase ratio averages about 1.2. Anhedral quartz commonly has undulose extinction and kink bands. Reddish-brown-colored biotite is the only mafic mineral and generally constitutes less than seven percent of the rock. Muscovite and biotite have about the same grain size and habit in undeformed rocks, but muscovite is significantly coarser-grained than biotite in ductile deformation zones developed in the Kootenay Landing Granite. Accessory minerals include garnet, monazite, apatite, zircon and ilmenite(?), but in general accessory minerals are rare.

Areal Extent of Bayonne Batholith Phases

The approximate areal extent of the various plutonic rock phases of the Bayonne batholith is shown in Figure 2. No direct contact between different phases was observed.

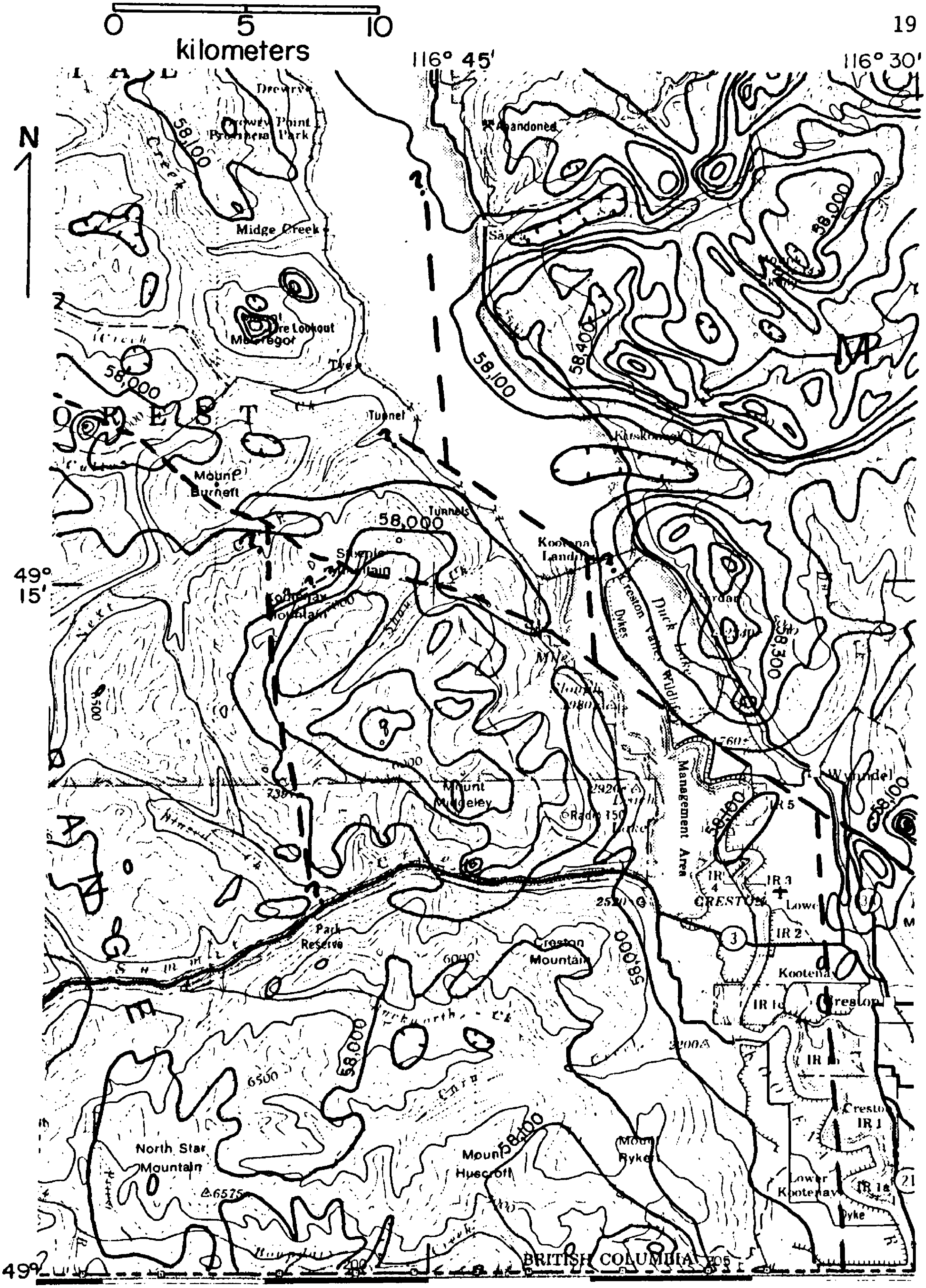
Contacts are drawn in part by interpreting aeromagnetic maps (GSC maps 8475G and 8476G). Figure 4 shows absolute total magnetic field contours and contacts inferred from them. Locating these contacts with aeromagnetic anomalies is possible because the main mass of the Bayonne batholith contains abundant accessory magnetite, whereas in the Kootenay Landing Granite and Mine stock it is rare or absent.

A contact between the Kootenay Landing Granite and the main mass of the Bayonne batholith can be located within several hundred meters just south of Kootenay Lake on its west side. The contact inferred from the aeromagnetic anomalies is consistent with that located on the ground. The postulated intrusive contact in the vicinity of Kootenay Mountain and Steeple Mountain (see Figs. 2 and 4) is inferred solely from the magnetic evidence. Fault contacts inferred from aeromagnetic anomalies are discussed in following sections.

Age of the Bayonne Batholith

Glover (1978) and Archibald and others (1977) report that geologic relationships and K-Ar age determinations on micas indicate that the Mine stock and the main mass of the Bayonne batholith are of different age. Biotite from the contact aureole of the Mine stock yields a K-Ar date of 150 Ma, but, by structural and compositional analogy with the

Figure 4. Absolute total magnetic field contours and contacts inferred from them. Contour interval 100 gammas. Aeromagnetic data from GSC maps 8475G and 8476G.


0
5
10
kilometers
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116° 45'
116° 30'
49° 15'
49°
Drewry Point Provincial Park
Midge Creek
Abandoned
58,100
58,000
58,400
58,300
Tunnel
Tunnels
Mount Burnett
Kootenay Landing
Creston Valley Wildlife Management Area
Duck Lake
Dykes
Mount Midgeley
Radio 150
Wynndel
IR 5
IR 3
IR 2
CRESTON
Park Reserve
Creston Mountain
North Star Mountain
Mount Huscroft
Mount Ryke
Lower Kootenay
BRITISH COLUMBIA
6500
6000

Nelson batholith, the plutons may be as old as middle Jurassic (Archibald and others, 1977). A 171 Ma U-Pb zircon date determined by Archibald (personal comm., 1981) from the Mine stock supports a middle Jurassic age.

The main mass of the Bayonne batholith yields K-Ar dates which suggest emplacement of most of that phase at about 95-100 Ma (Archibald, personal comm., 1981). As is discussed below, the Kootenay Landing Granite was probably emplaced shortly prior to this date. Hence this date may represent a reset event rather than an emplacement age.

The Kootenay Landing Granite is compositionally nearly identical to the core phase of the White Creek batholith. The striking similarity between these two bodies which are 65 kilometers apart suggests that they were emplaced during the same event, hence approximately at the same time. Wanless and others (1968) present an exhaustive geochronologic study of the White Creek batholith. A Rb-Sr whole rock isochron based on five points indicates a minimum emplacement age for the core phase of 111 Ma.

Archibald (personal comm., 1981) reports eleven K-Ar mica age determinations from seven two-mica rock localities, presumably all from the Kootenay Landing Granite. Sample locations and age determinations are shown on Figure 2. Seven biotite ages range from 40-51 Ma and four muscovite ages range from 49-54 Ma. Mica pairs from the same samples are discordant. The mid-Cretaceous minimum age of emplacement for the Kootenay Landing Granite inferred by comparison with the core phase of White Creek batholith and the mica-pair discordance suggest that these dates record a late cooling or reset event (Archibald and others, 1977).

Regional Igneous Petrology

Regional correlation. A strong distinction exists between the Kootenay Landing Granite and the other phases of the main mass of the Bayonne batholith and the Mine and Wall stocks. Contrasts are evident in macroscopic to microscopic textures, major mineral constituent modes and compositions and occurrences of minor and accessory mineral constituents. These contrasts are outlined in Table 2.

The petrologic distinction observed in the Bayonne batholith exists throughout the Selkirk-Priest River region, a region which lies north of Spokane, Washington between 116° and 118° West longitude. Geologically the region lies generally east and southeast of the Kootenay Arc. The Kootenay Landing Granite correlates petrologically with plutons of the two-mica suite identified by Miller and Engels (1975) in northeastern Washington and northern Idaho and with the core phase of the White Creek batholith (Reesor, 1958; Wanless and others, 1968; Mursky, 1972) located about 65 kilometers north-northeast of the Bayonne batholith (see Fig. 1). All other phases of the Bayonne batholith correlate petrologically with plutons of the hornblende-biotite suite identified by Miller and Engels (1975) and with the border phases of the White Creek batholith. A comparison of features noted throughout the region for these distinctive plutonic rock types is shown in Table 2.

S-type and I-type granites. The distinction in plutonic rock types noted above corresponds to the S-type versus I-type distinction made by

Feature	S-type Kootenay Landing Granite(X) Two-mica suite(O) Core phase, White Creek batholith(Y)	I-type Bayonne batholith, main mass and Mine stock(X) Hornblende-biotite suite(O) Border phases, White Creek batholith(Y)
potassium feldspar	microcline only (X,O,Y)	microcline and orthoclase (X,O,Y)
plagioclase	unzoned, lower An content (X,Y)	zoned, higher An content (X,Y)
color index	less than 10 (X,O,Y)	about 20 (X,O,Y)
muscovite	present (X,O,Y)	absent (X,O,Y)
hornblende	absent (X,O,Y)	present (X,O,Y)
epidote	absent (X,O,Y)	present (X,O,Y)
biotite	reddish-brown pleochroism (X,Y)	greenish-brown pleochroism (X,Y)
monazite	present (X,Y)	absent (X,Y)
sphene	absent (X,O,Y)	present (X,O,Y)
magnetite	absent (X,Y)	present (X,Y)
rutile	absent (X,Y)	present (X,Y)
allanite	present (O,Y)	absent (O,Y)
ilmenite	common (X,Y)	rare (X,Y)
foliation	common (X,O,Y)	rare (X,O,Y)
porphyritic	rarely (X,O,Y)	commonly (X,O,Y)
composition	heterogeneous (X,O,Y)	homogeneous (X,O,Y)
pegmatite dikes	abundant (X,O,Y)	common (X,O,Y)
total accessories	much lower (X,Y)	much higher (X,Y)

Table 2. Comparison of characteristic features of two distinctive plutonic rock suites corresponding to the S-type and I-type granites of Chappell and White (1974). References:
(X) this study
(O) Miller and Engels (1975); F. Miller, personal comm., 1981
(Y) Reesor (1958); Wanless and others (1968); Mursky (1972).

Chappell and White (1974). The distribution of S- and I-type plutons is shown in Figure 1. In this study, the S-type versus I-type distinction is made mineralogically. S-type granites typically contain muscovite, monazite and ilmenite and lack hornblende, epidote, sphene and magnetite, whereas the opposite is true for the I-type granites. Other distinguishing characteristics of S- and I-type granites are shown in Table 3.

The assignment of the core phase of the White Creek batholith to the S-type category is confirmed by the initial Sr isotopes (Wanless and others, 1968). A Rb-Sr whole-rock isochron drawn through five points indicates an initial $^{87}Sr/^{86}Sr$ ratio of 0.7250, suggesting a continental crust source for the magma.

Chappell and White (1974) attribute the S-type versus I-type distinction to a difference in composition of the source region for the granitic magmas. They conclude that S-type magmas are derived by partial melting of sedimentary rock and I-type magmas are derived by partial melting of igneous rocks. Later work tends to favor a primitive mantle-derived source for I-type magmas and a continental crust source for the S-type magmas (e.g. Beckinsale, 1979; McCulloch and Chappell, 1982). The effects of differentiation and contamination of the primary magma complicate any interpretation of source rock composition, and it is evident that the mixing of mantle-derived and continental crust components is a common occurrence (McCulloch and Chappell, 1982).

Feature	I-type	S-type
Felsic-mineral differences	quartz less abundant; feldspar may be pink	quartz more abundant; feldspar commonly white
Common mafic mineral	biotite high in Mg/Fe	biotite low in Mg/Fe
Distinctive minor minerals	± pyroxene, epidote, allanite, hornblende	± garnet, sillimanite, cordierite, muscovite
Opaque minerals	magnetite ± ilmenite ± pyrite	ilmenite (0.1%) ± pyrrhotite, graphite
Accessory minerals	sphene common	sphene secondary only
SiO_2	55-76%	66-76%
Na_2O	>2.2% in rocks with 2.0% K_2O to 3.2% in rocks with 5.0% K_2O	<2.2% in rocks with 2.0% K_2O to 3.2% in rocks with 5.0% K_2O
Mol $Al_2O_3/(Na_2O + K_2O + CaO)$	<1.1	>1.1 (peraluminous)
C.I.P.W. Norms	<1.0% "corundum" or diopside present	>1.0% "corundum"
Minor and trace elements at 66% SiO_2	$TiO_2 > 0.55\%$ $CaO > 3.7\%$ $Cr < 45$ ppm $Co < 16$ ppm $Zr < 150$ ppm	$TiO_2 < 0.55\%$ $CaO < 3.7\%$ $Cr > 45$ ppm $Co > 16$ ppm $Zr > 150$ ppm
Sr^{87}/Sr^{86}	<0.706	>0.706
Mineral deposits	porphyry Cu-Mo	Sn,W
Xenoliths	igneous appearance and normally hornblende-bearing	metasedimentary; may be common
Interpreted oxygen fugacity	higher, $Fe_2O_3/FeO > 0.4$	lower, $Fe_2O_3/FeO < 0.4$

Table 3. Distinguishing characteristics of I- and S-type granitic rocks. From Chappell and White (1974); White and Chappell (1977); Ishihara (1977); Hine and others (1978). After Hyndman (in prep.).

Spatial Separation of S- and I-type Granites

S- and I-type plutons in the Selkirk-Priest River region have overlapping geographic domains. If S-type granitic magmas are derived by partial melting of continental crust, then this entire region must be underlain by continental crust. The I-type magmas in the region may have been derived by partial melting in the underlying mantle, as proposed for the late I-type plutons intruding the predominantly S-type western portion of the Idaho batholith (Hyndman, in press).

The plutonic history of the Selkirk-Priest River region differs markedly from that of the opposite side of the Kootenay Arc. Voluminous batholiths such as the Nelson and Kuskanax are inferred to have been emplaced during the Jurassic on the concave side of the Kootenay Arc, but batholiths of that age are not known to occur in the Selkirk-Priest River region on the convex side of the Kootenay Arc (see Tectonic Assemblage Map of the Canadian Cordillera, GSC map 1505A). In addition to this contrast in age of emplacement, S-type granitic plutons characteristic of the Selkirk-Priest River region on the convex side of the Kootenay Arc are not known to occur on the concave side of the Kootenay Arc. A spatial separation of terranes dominated by S- and I-type intrusions is noted for the Lachlan Fold Belt of southeastern Australia (White and others, 1976) and the Idaho batholith (Hyndman, in press). The line separating the two terranes may represent the position of the continental-oceanic crust boundary in these regions (White and others, 1976; Hyndman, in press). If S-type granites are the result of the partial melting of continental crust, the Kootenay Arc may mark the edge of the autochthonous Precambrian continental crust of the North American craton. Using different geologic parameters, Price (1980) reached the same conclusion for the central portion of the Kootenay Arc (see page 6). Defining the edge of the North American craton by the most westerly occurrence of S-type granites is analogous to defining the same boundary by the most westerly occurrence of initial Sr^{87}/Sr^{86} ratios greater than 0.706 (Kistler and Peterman, 1973; Armstrong and others, 1977).

As noted above, the southwesterly portion of the Kootenay Arc is northeast-trending (see Fig. 1) and lies approximately along the projection of the St. Mary fault and a major crustal structure identified geophysically by Kanasewich and others (1969). If the southwesterly portion of the Kootenay Arc marks the edge of the autochthonous North American continental crust, the alignment of that boundary with a major crustal structure suggests that the presumed Precambrian rifting of the North American craton (eg. Stewart, 1972) may have occurred in this vicinity along a preexisting crustal weakness. Because of this alignment and lacking any evidence to the contrary, the continental crust inferred to underlie the Selkirk-Priest River region is assumed to be an autochthonous portion of the Precambrian North American craton.

Temporal Separation of S- and I-type Granites

S-type and I-type granitic rocks are commonly separated in time of emplacement. Chappell and White (1974) note that the S-type plutons of the Lachlan Fold Belt of southeastern Australia are dominantly syntectonic, whereas the I-type plutons are dominantly post-tectonic.

The Older Granites of the British Caledonides are dominantly syntectonic, whereas the Newer Granites are post-tectonic and I-type (Pankhurst, 1979). Beckinsale (1979) used Rb-Sr geochronology to distinguish two S-type and two I-type intrusive events in southeast Asia.

In the Selkirk-Priest River region, no consistent syntectonic versus post-tectonic relationship has been described, radiometric age dating is equivocal regarding age of emplacement and intrusive relationships indicative of relative time of emplacement are known from only seven locations. Geologic evidence suggests, however, that three separate intrusive events may have occurred in the Selkirk-Priest River region and can be distinguished in the infrastructure of the Selkirk metamorphic core complex.

The oldest of 91 radiometric age determinations from probable S-type plutons in the Selkirk-Priest River region (Table 4) is 111 Ma from the White Creek batholith (Wanless and others, 1968). If all S-type plutons in the region were emplaced during the same event, I assume this date to be the approximate age for the event. Concordant K-Ar age determinations for three biotite-muscovite pairs from probable S-type plutons range from 99 to 102 Ma (Table 5) and support this assumption. Reesor (1973) reports biotite and muscovite K-Ar ages of 132 and 138 Ma respectively for the S-type eastern phase of the Bugaboo batholith (see Fig. 1). These are rejected as unreasonable ages because this phase contains inclusions of an older plutonic phase which yields a K-Ar biotite age of 100 Ma (Reesor, 1973), a reasonable age in light of the common occurrence

Table 4
Age determinations from probable S-type plutons in the Selkirk-Priest River region. See Figure 1 for location of named plutons.
] = mineral pairs, biotite listed first

Location	Reference	Method	Mineral	Date(Ma)
Bugaboo, eastern phase	Reesor, 1973	K-Ar	B	100
Horsethief Creek	"	"	B	108
Fry Creek	"	"	B	45]
"	"	"	M	63]
"	"	"	B	76
"	"	"	M	83
"	"	"	B	86]
"	"	"	M	91]
"	"	"	M	97
White Creek, core phase	Wanless and others, 1968	"	B	82]
"	"	"	M	80]
"	"	Rb-Sr	whole rock	111
Kootenay Landing Granite	Archibald, pers. comm.	K-Ar	B	51]
"	"	"	M	54]
"	"	"	B	43]
"	"	"	M	51]
"	"	"	B	40
"	"	"	B	45]
"	"	"	M	50]
"	"	"	B	41]
"	"	"	M	49]
"	"	"	B	49
Summit stock	"	"	B	102]
"	"	"	M	102]
48° 58',116° 43'	Miller and Engels, 1975	"	B	50
48° 59',116° 40'	"	"	B	53
49° 57',116° 36'	"	"	B	49
48° 50',116° 30'	"	"	M	49
48° 43',116° 29'	"	"	B	51
48° 46',116° 44'	"	"	B	53]
"	"	"	M	49]
48° 54',116° 46'	"	"	B	51]
"	"	"	M	53]
48° 57',116° 52'	"	"	B	69
48° 59',116° 54'	"	"	B	98]
"	"	"	M	93]
48° 58',116° 57'	"	"	B	104
48° 56',116° 57'	"	"	B	108
48° 42',116° 54'	"	"	B	87
48° 43',117° 04'	"	"	B	85
48° 46',117° 04	"	"	M	95
48° 48',117° 13'	"	"	B	97

Table 4, continued

Location	Reference	Method	Mineral	Date(Ma)
48° 43',117° 20'	Miller and Engels, 1975	K-Ar	B	101
"	"	"	M	101
48° 45',117° 28'	"	"	B	78
"	"	"	M	86
48° 47',117° 31'	"	"	B	91
"	"	"	M	96
48° 44',117° 33'	"	"	B	92
48° 39',117° 30'	"	"	B	79
"	"	"	M	84
48° 36',117° 22'	"	"	B	51
48° 35',117° 21'	"	"	B	49
"	"	"	M	56
48° 36',117° 04'	"	"	B	91
"	"	"	M	94
48° 38',116° 48'	"	"	B	48
48° 36',116° 38'	"	"	B	49
48° 37',116° 26'	"	"	B	49
"	"	"	M	49
48° 29',116° 33'	"	"	B	47
"	"	"	M	49
48° 05',116° 41'	"	"	B	45
47° 56',117° 00'	"	"	B	46
47° 51',117° 10'	"	"	B	47
"	"	"	M	49
47° 51',117° 11'	"	"	B	47
"	"	"	M	47
47° 47',117° 28'	"	"	B	48
"	"	"	M	53
48° 24',116° 58'	"	"	B	93
"	"	"	M	100
48° 24',116° 51'	"	"	B	95
"	"	"	M	97
48° 27',116° 45'	"	"	B	48
"	"	"	M	48
48° 25',117° 08'	"	"	B	99
"	"	"	M	100
48° 26',117° 23'	"	"	B	48
"	"	"	M	50
48° 12',117° 30'	"	"	B	55
"	"	"	M	56
48° 00',117° 34'	"	"	M	78
48° 23',117° 35'	"	"	B	52
"	"	"	M	58
48° 24',117° 37'	"	"	B	56
"	"	"	M	67
48° 30',117° 40'	"	"	B	59
"	"	"	M	84
48° 31',117° 40'	"	"	B	74
"	"	"	M	89

of 90-100 Ma K-Ar dates in the region (see page 72). I-type plutons in the region commonly yield discordant K-Ar dates in the 45-50 Ma and 90-100 Ma ranges, but they also yield much older, commonly discordant dates (Reesor, 1973; Miller and Engels, 1975). I-type plutonic rocks, however, yield radiometric age determinations suggesting an Eocene emplacement age for some of them. This evidence includes concordant Eocene hornblende and biotite K-Ar dates from the Silver Point Quartz Monzonite (Miller and Engels, 1975) and Eocene dates from apparently shallow level I-type porphyritic dikes near Sandpoint (Harrison and others, 1972). These observations are consistent with a protracted(?) pre-111 Ma I-type intrusive event followed by an S-type intrusive event followed in the Eocene by the intrusion of the I-type Silver Point Quartz Monzonite. The data do not prove such a relationship, however, because these radiometric determinations may not represent emplacement ages.

Six observed intrusive relationships indicate that S-type intrusion followed I-type intrusion. The six are:

1) White Creek batholith, S-type core phase cross cuts contacts of older I-type border phases (Reesor, 1958),
2) S-type granodiorite intrudes older I-type Fan Lake granodiorite (Miller, 1974d, p. 4),
3) I-type Starvation Flat Quartz Monzonite older than S-type granodiorite (Miller and Clark, 1975, p. 38),
4) the S-type eastern phase of the Bugaboo batholith contains inclusions of the older I-type western phase (Reesor, 1973),

5) small dikes of an S-type quartz monzonite extend into an older I-type granodiorite a few tens of feet in northern Lincoln County, Washington (Becraft and Weis, 1963, p. 25), and

6) an S-type pluton appears to have a chilled margin against an older I-type pluton in northern Pend Orielle County, Washington (F. Miller, personal comm., 1982).

In addition, contact configurations shown by Miller and Engels (1975) for the area structurally overlying the Newport fault and north of Lat. 48°30' suggest that S-type plutons are younger, assuming that plutons generally have concave inward contacts (see Fig. 1).

A single intrusive relationship observed near Sandpoint, Idaho indicates that I-type intrusion followed S-type intrusion (Harrison and others, 1972). The fine-grained groundmass noted for the I-type pluton suggests that it may have been intruded at shallower levels and, hence, in a more recent event than most I-type plutons in the region. The determination of relative timing of pluton emplacement based on the distinction in groundmass grain size can apply only to plutons of the infrastructure of the Selkirk metamorphic core complex, because the presently exposed levels of infrastructure and suprastructure may have moved through the depth at which a fine-grained groundmass can form at different times. For this reason, plutons with fine-grained groundmass of apparent widespread occurrence east of the Purcell Trench (Harrison and others, 1972) are not a factor in this discussion.

The Silver Point Quartz Monzonite is an I-type pluton with fine-grained groundmass, and Miller (1974a) concludes that it is the youngest pluton in the region. As noted above, this pluton yields concordant Eocene K-Ar hornblende and biotite ages, the youngest in the region. This evidence supports the interpretation that I-type plutons with fine-grained groundmass were emplaced during the most recent intrusive event in the infrastructure of the Selkirk metamorphic core complex.

Evidence presented in this section suggests that three separate, distinguishable intrusive events occurred in the infrastructure of the Selkirk metamorphic core complex. This speculation would not be warranted without the knowledge that elsewhere in the world S-type and I-type intrusive events are commonly separated temporally. A protracted(?) pre-mid-Cretaceous I-type intrusive event was followed in mid-Cretaceous time by an S-type intrusive event. Following a period of uplift and/or cooling, Eocene I-type plutons with fine-grained groundmass were emplaced.

CHAPTER 3

STRUCTURAL GEOLOGY

A zone of ductile and cataclastic deformation has developed in rocks of the Kootenay Landing Granite at the south end of Kootenay Lake on the west side of the Purcell Trench. The location of this zone of deformation is shown on Figure 2. Exposure of the deformation zone is excellent in railroad cuts and along the lake shore. The deformation zone is exposed at lake level in two outcrops located two kilometers apart. The following analysis pertains specifically to the better exposed northern end of the deformation zone.

Ductile Deformation

Mesoscopic and macroscopic description. In the deformation zone at the south end of Kootenay Lake, mylonites have developed in a protolith of Kootenay Landing Granite. The term mylonite is used here as defined by Bell and Etheridge (1973). Mylonites reflect ductile deformation wherein strain is accompanied by - if not accommodated by - recovery and recrystallization of mineral grains. Cataclasites with evidence of fractured grains reflect deformation of brittle rocks. Ductile deformation is favored over brittle deformation by high confining pressures, high temperatures and low strain rates (Jaeqer and Cook, 1976, p. 85-88).

Two distinct textural varieties of mylonite, one strongly developed and the other more weakly developed, exist near Kootenay Landing. The more strongly developed mylonites are recognized in the field as fine-grained shear zones with feldspar augen. The shear zones have a strong foliation defined by flattened rods of quartz and feldspar, alternating bands rich in mafic and felsic minerals and a preferred orientation of biotite. As shown in Figure 5, the strongly developed variety of mylonite has an attitude of about N5°W, 40°E. The strongly developed mylonites also have a distinct lineation defined by elongate mineral grains, principally muscovite, and elongate rods of quartz and feldspar. As shown in Figure 6, this lineation trends consistently N70-75°E. The more strongly developed, east-dipping mylonites are restricted to a narrow zone. In the more northerly outcrop of the ductile deformation zone, five discrete mylonite shears varying in thickness from 15 to 45 cm with an aggregate thickness of 2.5 meters are separated by undeformed granite over a width of 12 meters perpendicular to the shears. The northern and southern exposures of this narrow zone lie two kilometers apart at lake level precisely along the N5°W strike of the east-dipping mylonite foliation.

The narrow zone of east-dipping mylonites disappears under the lake or lake sediments in both directions along strike, but the persistence of this zone exposed two kilometers apart exactly along the strike of the east-dipping mylonite foliation suggests that the zone should continue. A projection to the south of the N5°W, 40°E structural trend of the zone of strongly developed mylonites predicts that the zone should be exposed on the ridge bordering the north side of Newington Creek.

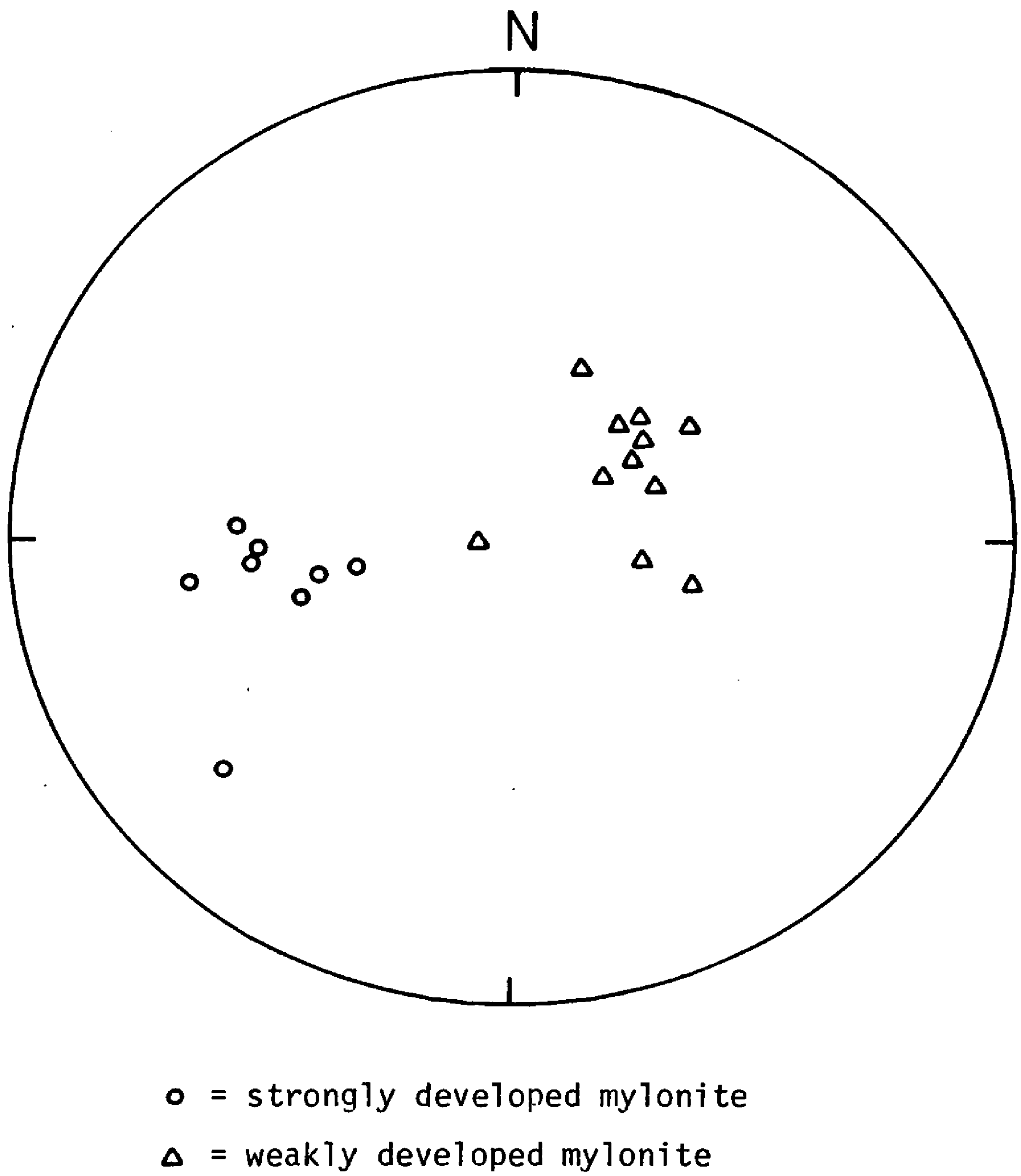
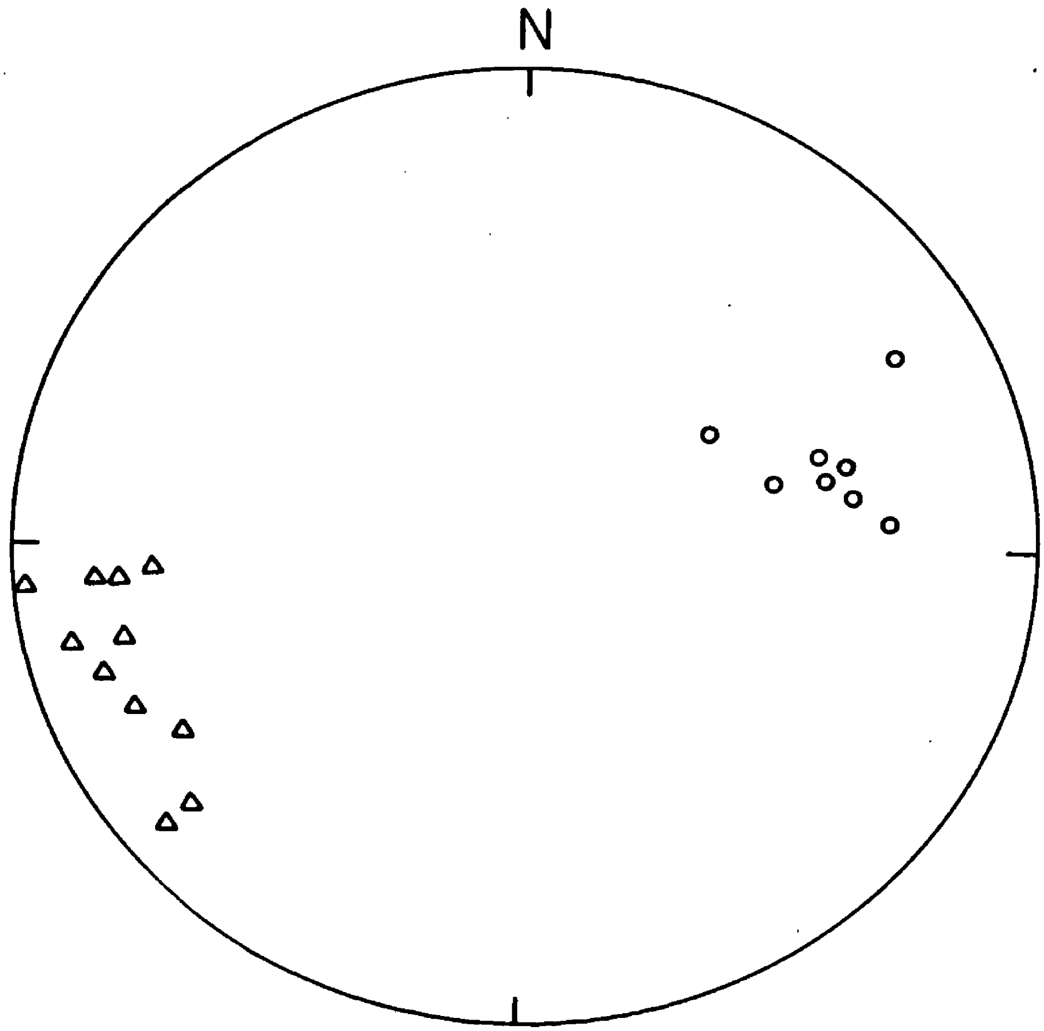


Figure 5. Equal-area projection of 19 poles to mylonite foliation from the deformation zone exposed near Kootenay Landing.



o = strongly developed mylonite

Δ = weakly developed mylonite

Figure 6. Equal-area projection of 19 mylonite lineations from the deformation zone exposed near Kootenay Landing.

Outcrop is good along that ridge, but no evidence of the east-dipping structure was found. In addition, rocks of the main mass of the Bayonne batholith outcrop on that ridge. This evidence suggests the existence of a younger cross-fault in this vicinity. An aeromagnetic anomaly trending about N55°W (see Fig. 4) may correspond with this postulated fault (Fig. 2).

Mylonites of the more weakly developed variety are not strongly penetrative. Typically, 1 mm-wide shears are separated by 1 cm of much less deformed granite protolith in zones of 10 to 30 cm thickness. The quartz in this less deformed protolith is inferred relict in a following section. Foliation in the more weakly developed mylonites is defined by the thin, fine-grained shears themselves. Locally this foliation is curviplanar, possibly as a result of drag-folding along the slickensided surfaces described below. As seen in Figure 5, the more weakly developed mylonites have a more variable orientation than the strongly developed mylonites but generally dip at shallow angles to the west. A lineation in the more weakly developed variety of mylonite is defined primarily by elongate muscovite grains. This lineation has a somewhat variable trend of about N70°E (Fig. 6). The west-dipping mylonites are not restricted to a narrow zone but rather are exposed about 600 meters structurally below and at least 200 meters above the zone of east-dipping mylonites.

Microscopic textures. Thin sections of samples from the centers of the east-dipping mylonites show evidence of strong ductile deformation (see Plate 1 and Fig. &). In the centers of the east-dipping shears

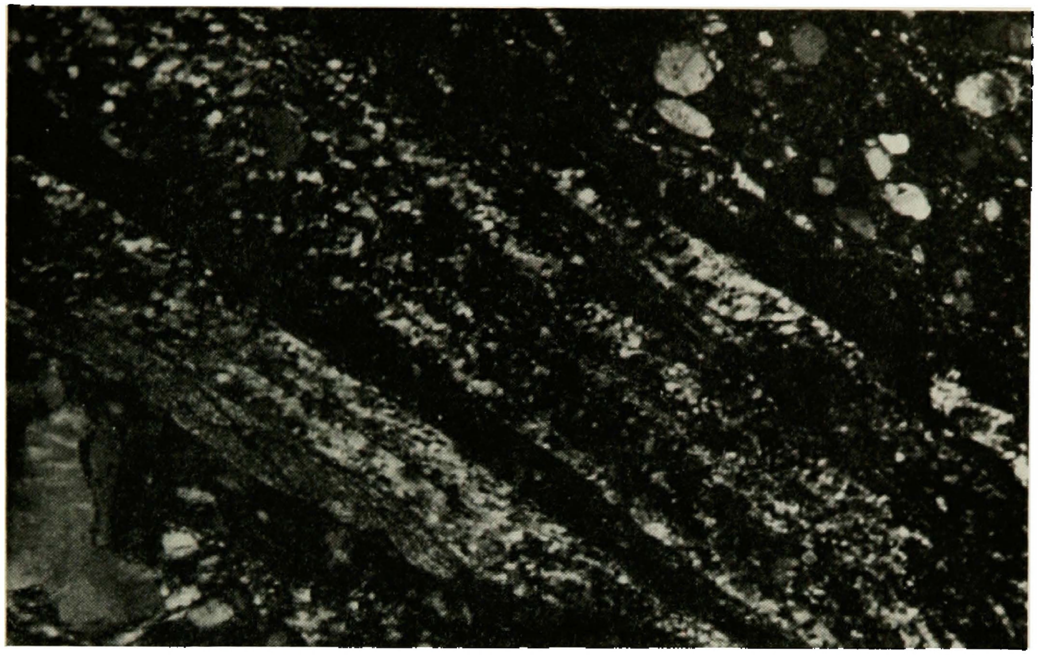


Plate 1. Photomicrograph showing textures typical of an east-dipping mylonite.

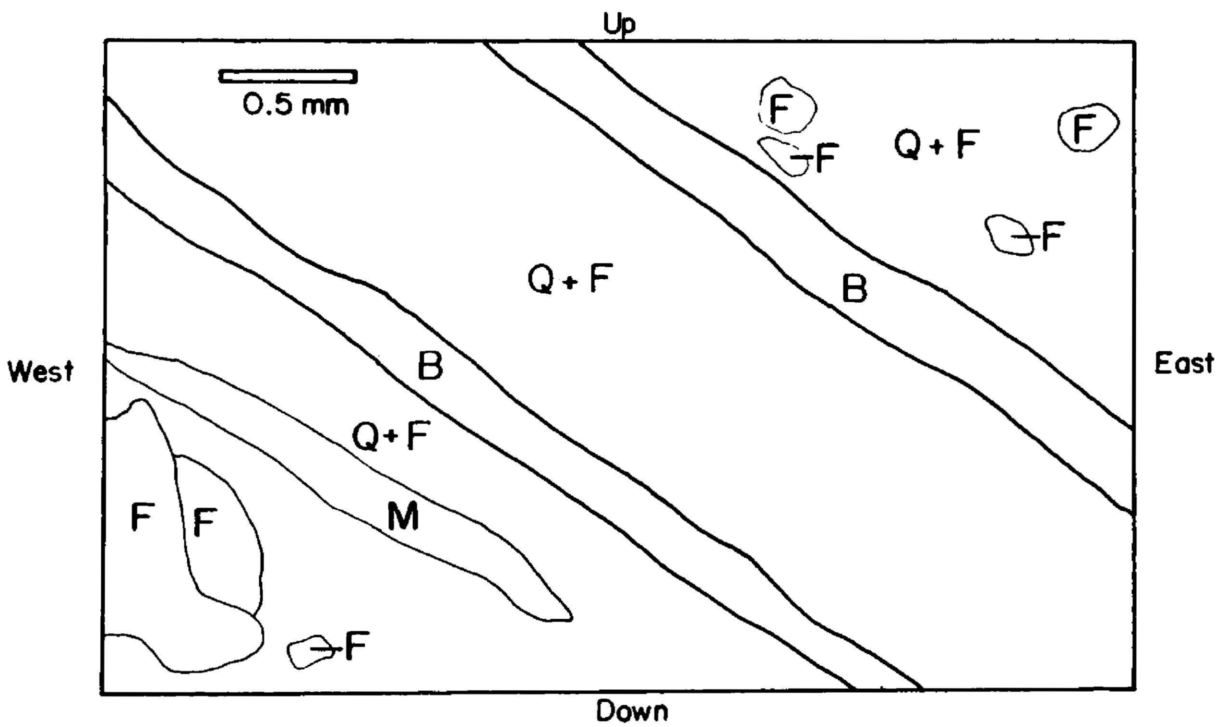


Figure 7. Diagram of Plate 1, approximate orientation shown. Note feldspar (F) and muscovite (M) porphyroclasts and alternating bands rich in very fine-grained mafic (B) and felsic (Q+F) minerals defining foliation.

compositional layering produced during deformation lies parallel to the schistosity defined by the preferred orientation of mineral grains, a relationship that develops only with high degrees of strain (Berthe and others, 1979). Medium-grained porphyroclasts of plagioclase, microcline and muscovite lie in a very fine-grained matrix of those same minerals plus biotite and quartz. Feldspars show deformation twin-lamellae and strain-free quartz has been entirely recrystallized. Lozenge-shaped muscovite porphyroclasts locally overgrow the foliation, but where muscovite cleavage planes lie about parallel to the foliation, individual grains are strongly elongate and flattened. This elongation partially defines the mesoscopic lineation and, as discussed below, indicates sense of shear. These textural relationships indicate that muscovite in the east-dipping mylonites crystallized or recrystallized after most of the deformation in the shears but underwent some late deformation.

Microscopic textures typical of the west-dipping mylonites are shown in Plate 2 and Figure 8. Subparallel thin shear zones defining the foliation are separated by regions of much less deformed granite protolith, and thus the shears are only weakly penetrative. In the thin shear zones, very fine-grained strain-free recrystallized quartz, feldspar, biotite and muscovite are present. Quartz grains in the shears are elongate and form a microstructure. The axis of elongation of these quartz grains lies at an angle of about 15° to the foliation. In the much less deformed regions between the thin shears, quartz shows undulose

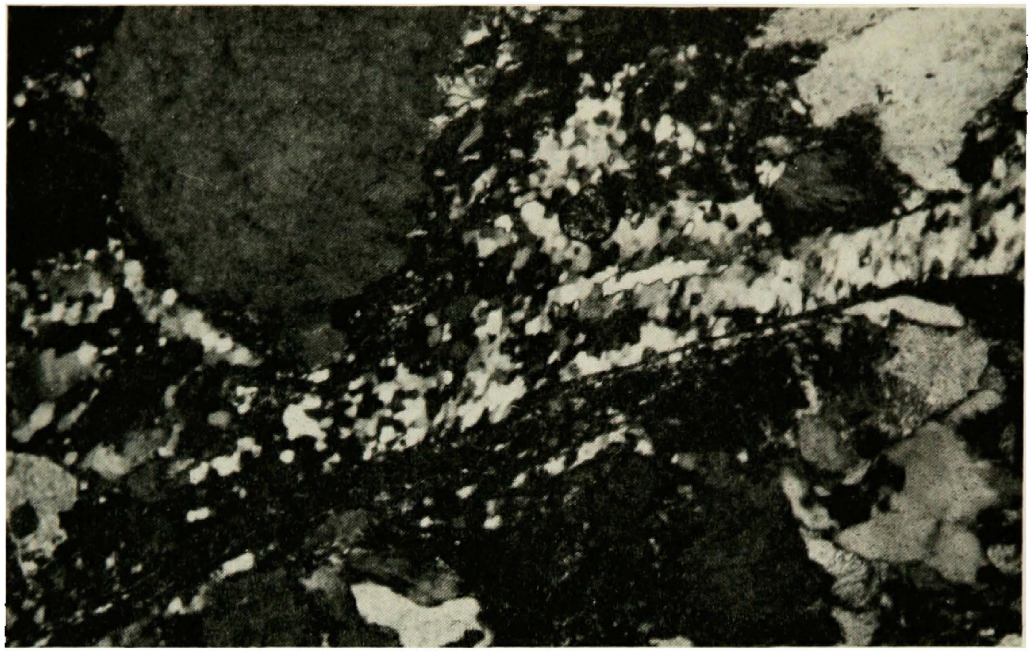


Plate 2. Photomicrograph showing textures typical of a west-dipping mylonite.

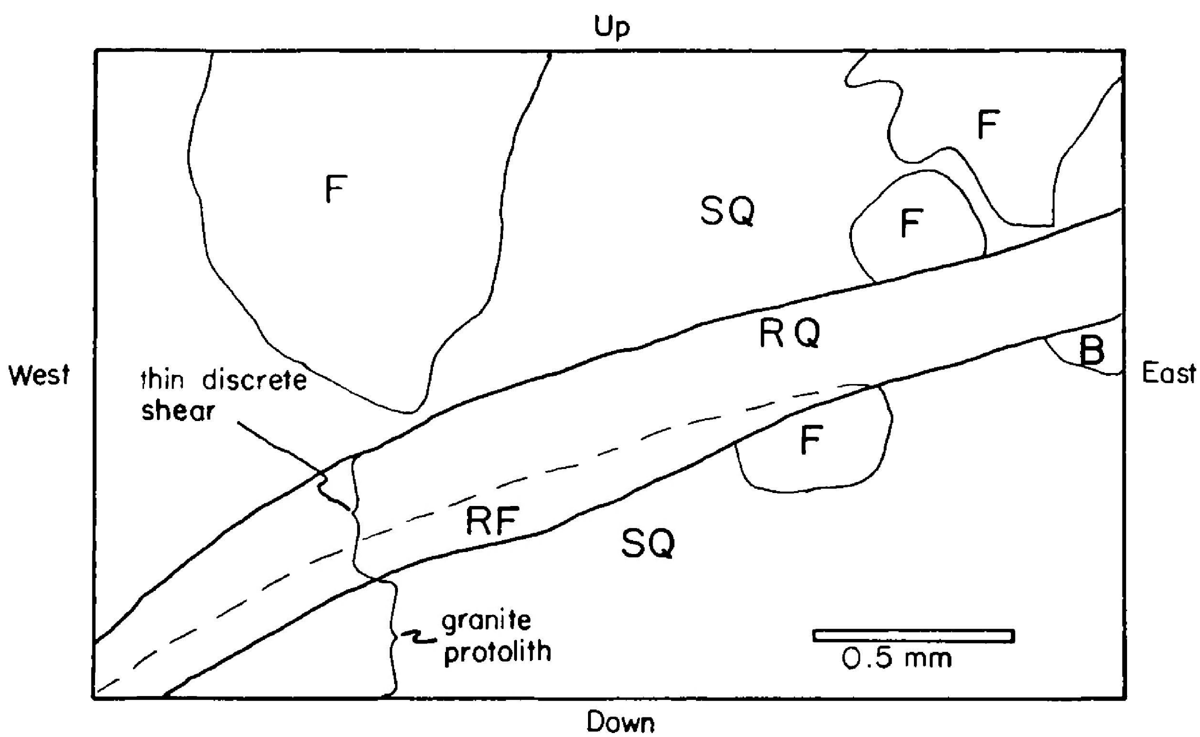


Figure 8. Diagram of Plate 2, approximate orientation shown. Note thin discrete shear zone with very fine-grained elongate quartz (RQ) and feldspar (RF) enclosed by granite protolith with quartz sub-grains (SQ) and weakly deformed feldspar (F).

extinction, deformation lamellae, polygonization and the development of sub-grains, indicating that deformation has not led to the recrystallization of the grains.

Indicators of sense of shear. Four fabric elements consistently indicate sense of shear in the mylonites near Kootenay Landing. The fabric elements are:

1) deformed muscovite books.

2) sigmoidal foliation around feldspar porphyroclasts,

3) comminution tails, and

4) preferred orientations of quartz c-axes.

The first and second elements can be seen at mesoscopic and microscopic scales, but the third and fourth are visible only at the microscopic scale. All fabrics were observed in slabs or thin sections cut parallel to the lineation and perpendicular to the foliation, indicating that at least the most recent movement was directed parallel to the lineation.

As noted above, mylonites at Kootenay Landing contain muscovite porphyroclasts that locally overgrow the foliation. This textural relationship indicates that muscovite crystallized or recrystallized after most, but not all, of the ductlie deformation producing the mylonites. Muscovite books oriented with their basal cleavages about parallel to the foliation are deformed into elongate, flattened shapes. In hand specimens broken parallel to the foliation plane, these deformed grains occur as streaks up to about 0.5 cm wide and 1.5 cm long with their long axes lying parallel to and partially defining the lineation.

In thin sections, muscovite elongation and flattening appears to be the result of displacement within the grain along cleavage planes. As shown in Plate 3 and, diagrammatically, in Figure 9, the apparent sense of displacement along those cleavage planes indicates sense of shear. Deformed muscovite books consistently indicate a normal sense of displacement for both east- and west-dipping mylonites relative to their present orientation.

Foliation defined by alternating bands of comminuted mineral grains wraps around feldspar porphyroclasts in the mylonites near Kootenay Landing. The foliation takes on a sigmoidal shape with monoclinic symmetry and indicates sense of shear (Plate 4 and Figure 10). Sigmoidal foliation around feldspar porphyroclasts consistently indicates a normal sense of displacement for the east-dipping mylonites relative to their present orientation.

During ductile deformation, recrystallization along kinks concentrated at grain edges results in a reduction in grain size (Bell and Etheridge, 1973). Comminuted new grains are pulled out into tails in a sense compatible with and indicative of the sense of shear displacement (Plate 5 and Figure 11). Comminution tails consistently indicate a normal sense of displacement for both east- and west-dipping mylonites relative to their present orientation.

Quartz c-axis fabrics have been determined for one oriented sample from an east-dipping mylonite and one from a west-dipping mylonite. Quartz c-axes in the east-dipping mylonite show a broad point maximum

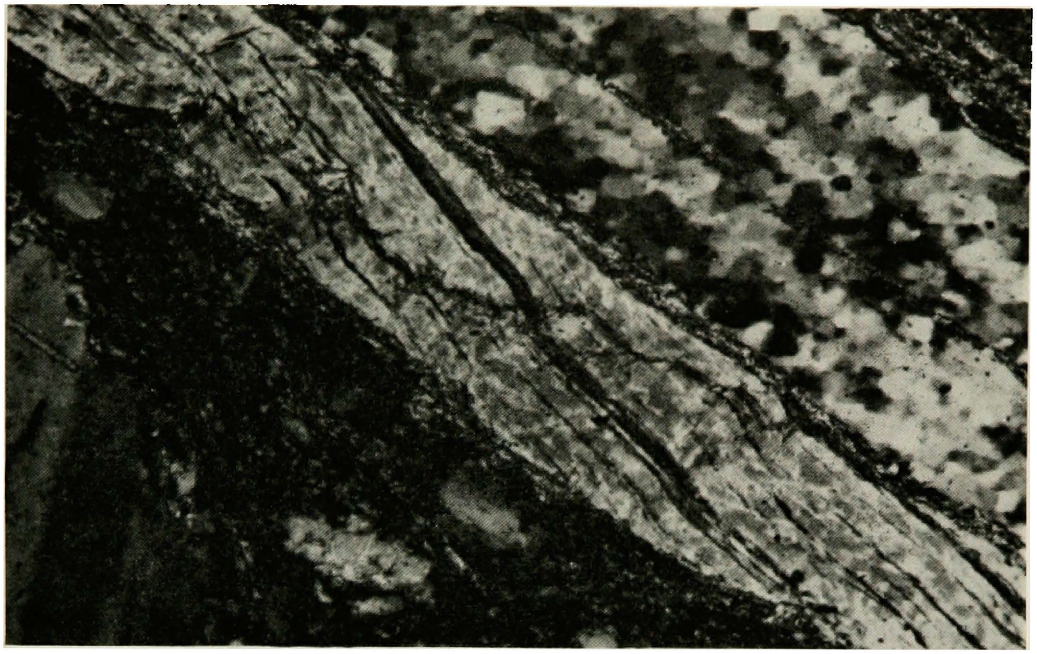


Plate 3. Photomicrograph showing a deformed muscovite book in an east-dipping mylonite.

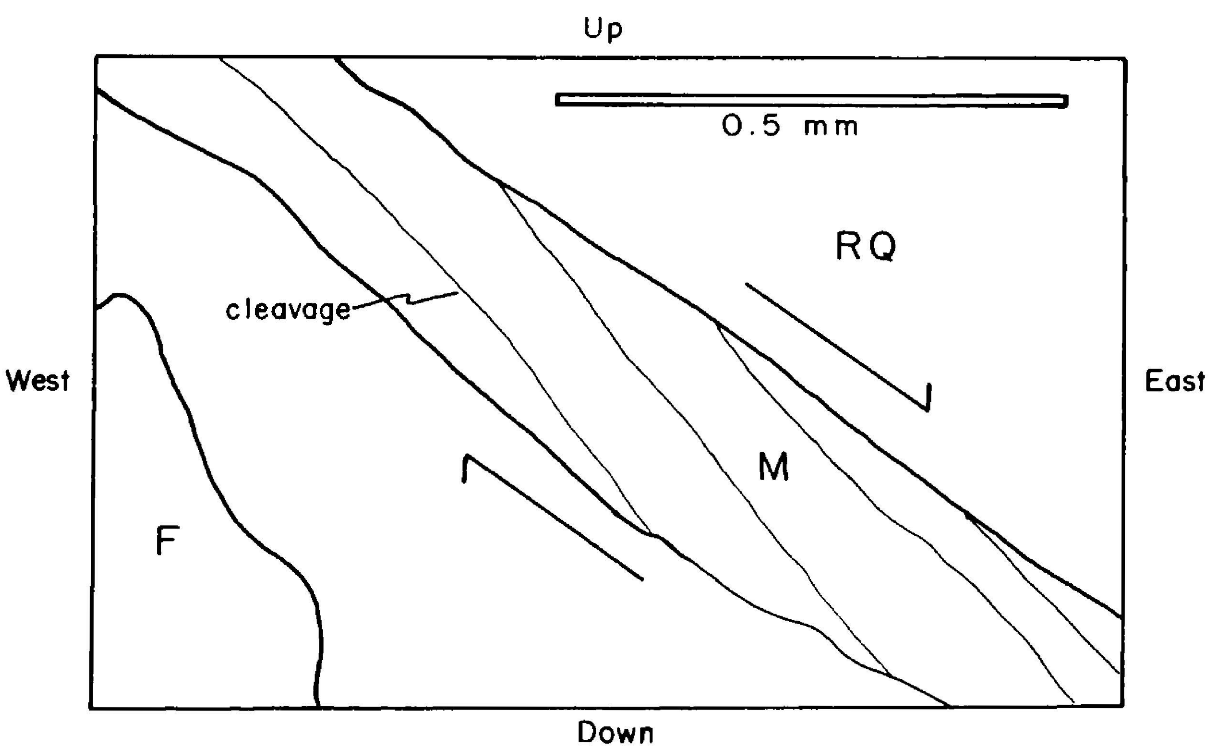


Figure 9. Diagram of Plate 3, approximate orientation and deduced sense of shear shown. Note elongate, flattened shape of muscovite porphyroclast (M) and apparent sense of displacement along cleavage planes.

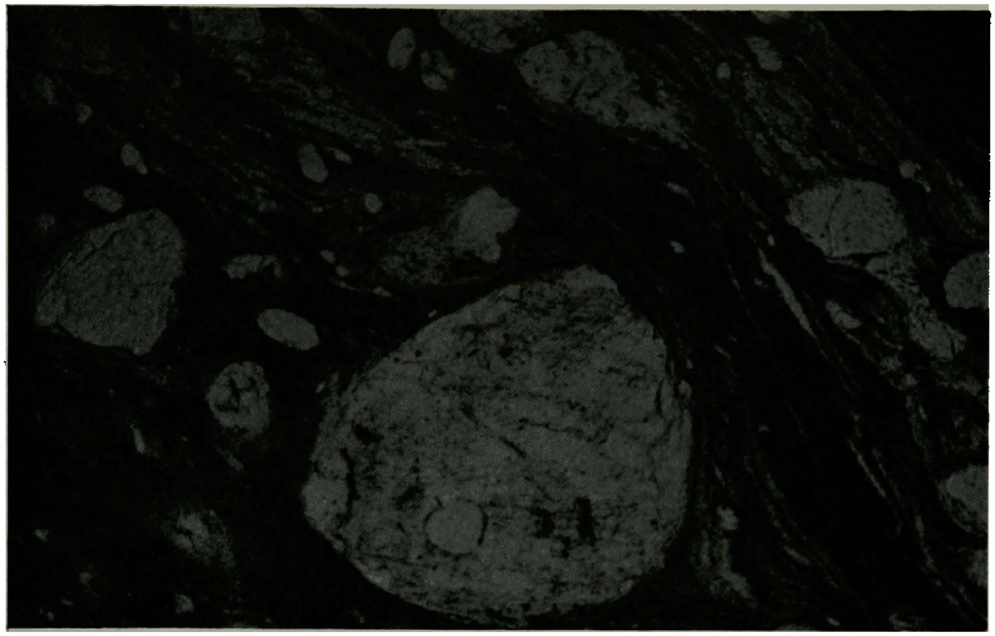


Plate 4. Photomicrograph showing sigmoidal foliation wrapped around feldspar porphyroclasts in an east-dipping mylonite.

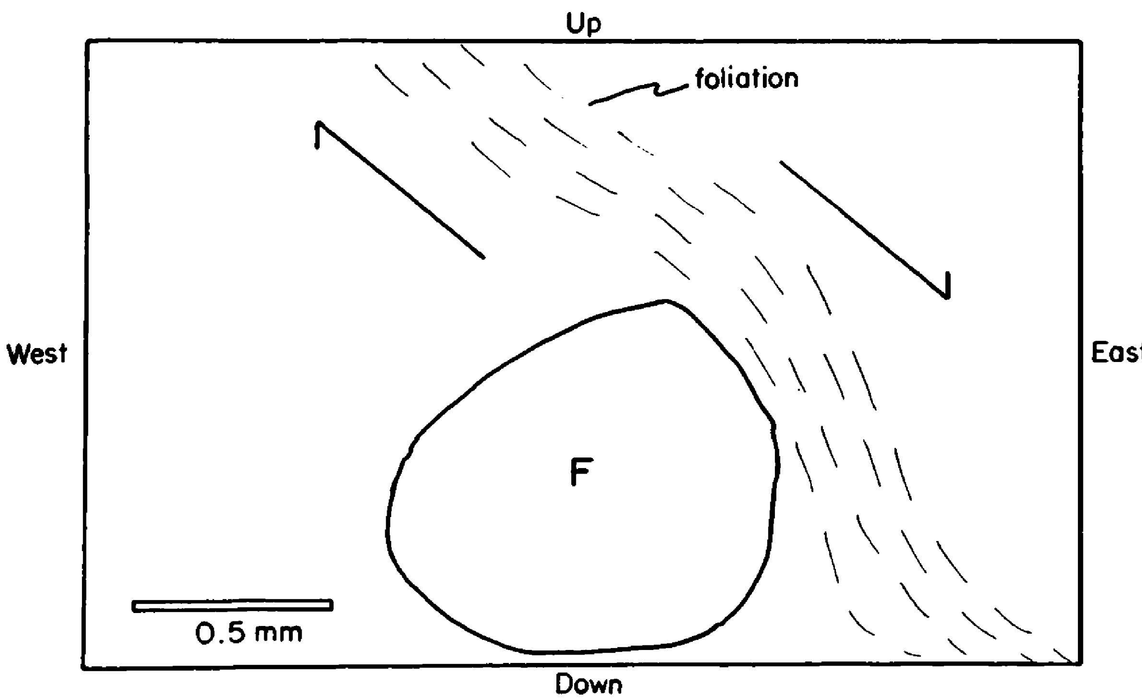


Figure 10. Diagram of Plate 4, approximate orientation and deduced sense of shear shown.

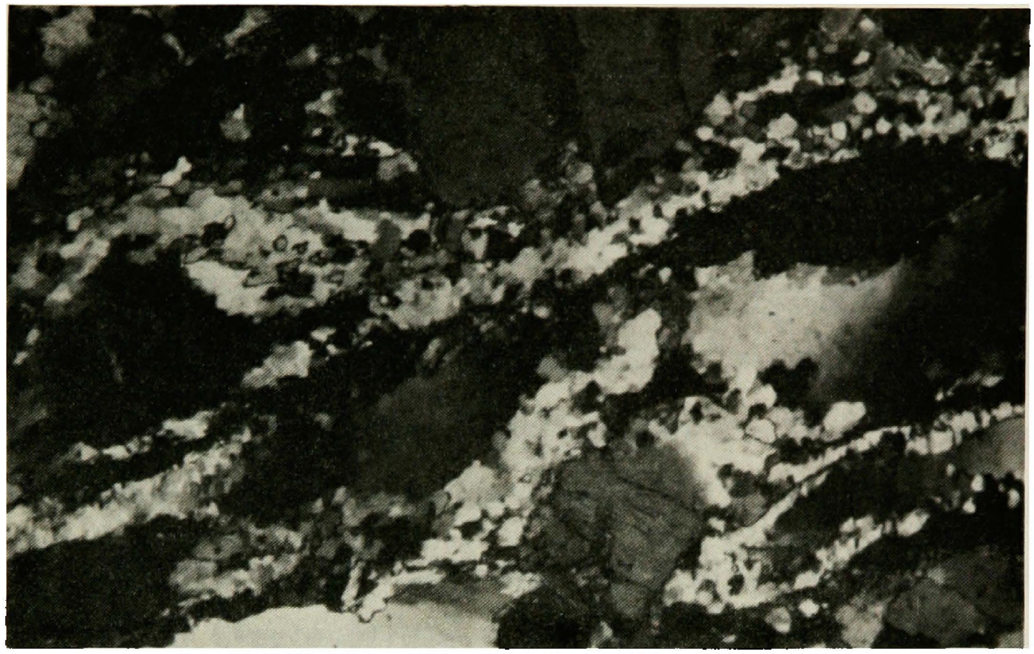


Plate 5. Photomicrograph showing comminution tails in a west-dipping mylonite.

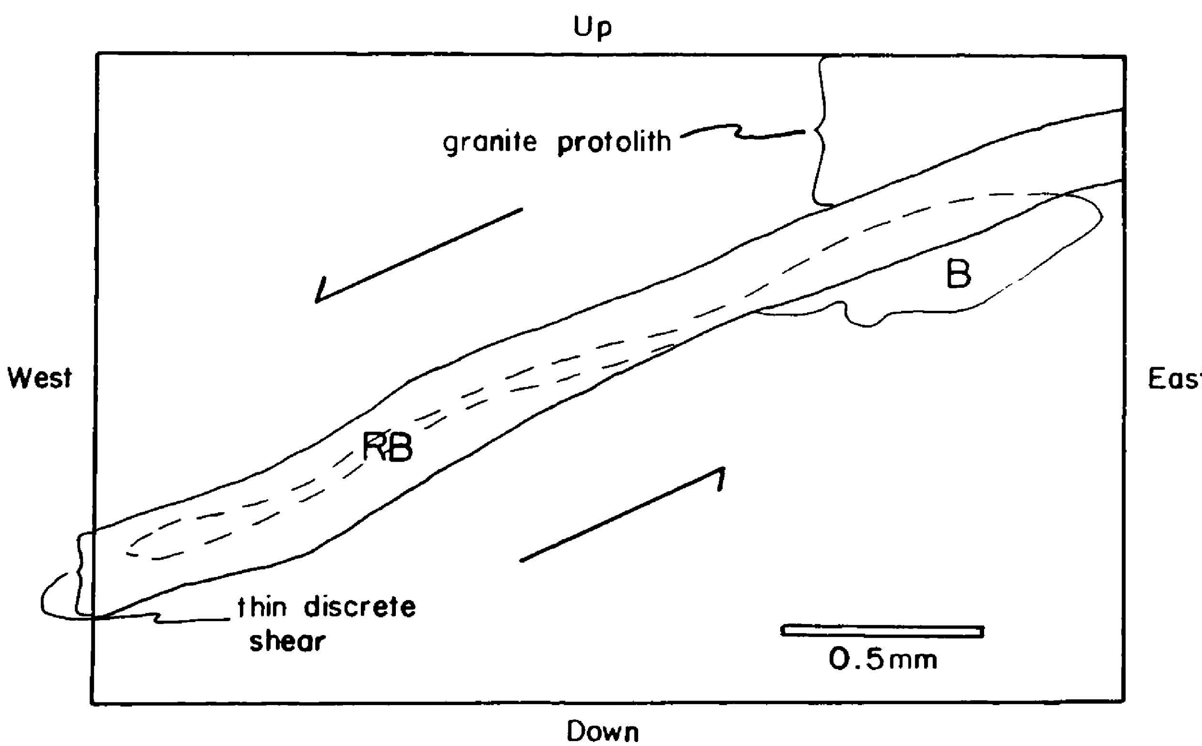


Figure 11. Diagram of Plate 5, approximate orientation and deduced sense of shear shown. Note biotite crystal in granite protolith (B) is recrystallized (RB) and pulled out into a tail in the thin discrete shear zone.

lacking symmetry relative to the foliation but define a diffuse crossed-girdle fabric with weak monoclinic symmetry relative to the foliation (Figure 12). This fabric may reflect a complex deformation history for the east-dipping mylonite, as discussed in a following section.

In the west-dipping mylonite sample, separate fabric determinations were made for elongate new quartz grains in the discrete shears and for relict quartz grains from the non-recrystallized granite protolith between the discrete shears. The elongate new grains in the discrete shears show a partial single-girdle fabric with weak monoclinic symmetry relative to the foliation plane (Fig. 13), whereas the relict grains show a random orientation (Fig. 14).

Quartz grains deformed under ductile conditions tend to take on a preferred crystallographic orientation. The symmetry of the crystallographic fabric measured on the U-stage is compatible with the symmetry of other related fabric elements and presumably, the symmetry of the deformation (Turner and Weiss, 1963, p. 385-386). Eisbacher (1970), Wilson (1975) and Carreras and others (1977), among others, note quartz c-axis fabrics with strong monoclinic symmetry from mylonites. Lister and Williams (1979) demonstrated with field evidence and computer simulations that the symmetry of this monoclinic fabric relative to the kinematic framework of flow plane and flow direction consistently indicates sense of shear as shown in Figure 15. Preferred orientations of quartz c-axes indicate a normal sense of displacement for both east- and west-dipping mylonites relative to their present orientation.

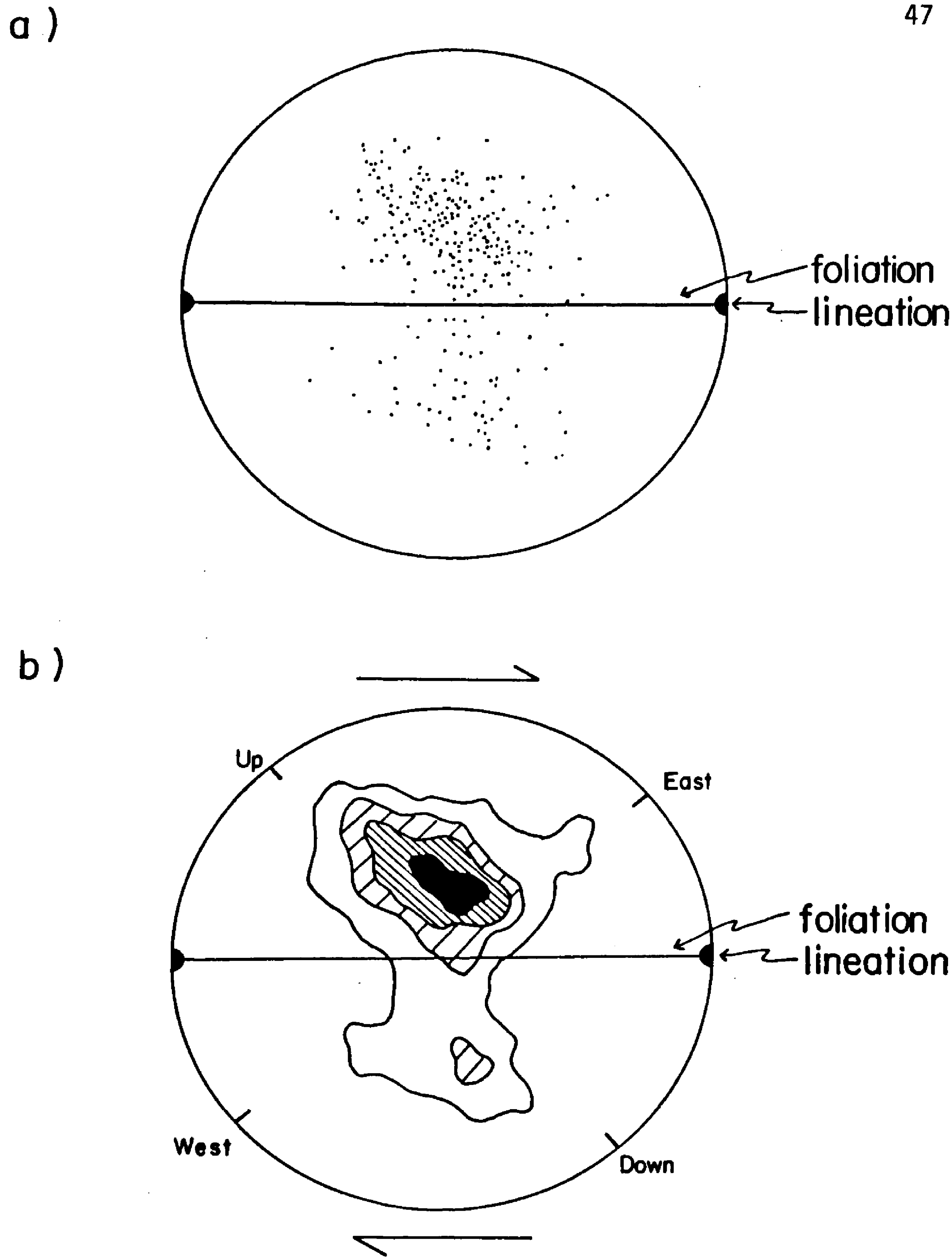


Figure 12. Equal-area projection of 260 quartz c-axes from sample 27, an east-dipping mylonite. Contours at 1, 3, 7 and 10 per cent (maximum 12 per cent) per 1 per cent area, deduced sense of shear and projection orientation shown in b).

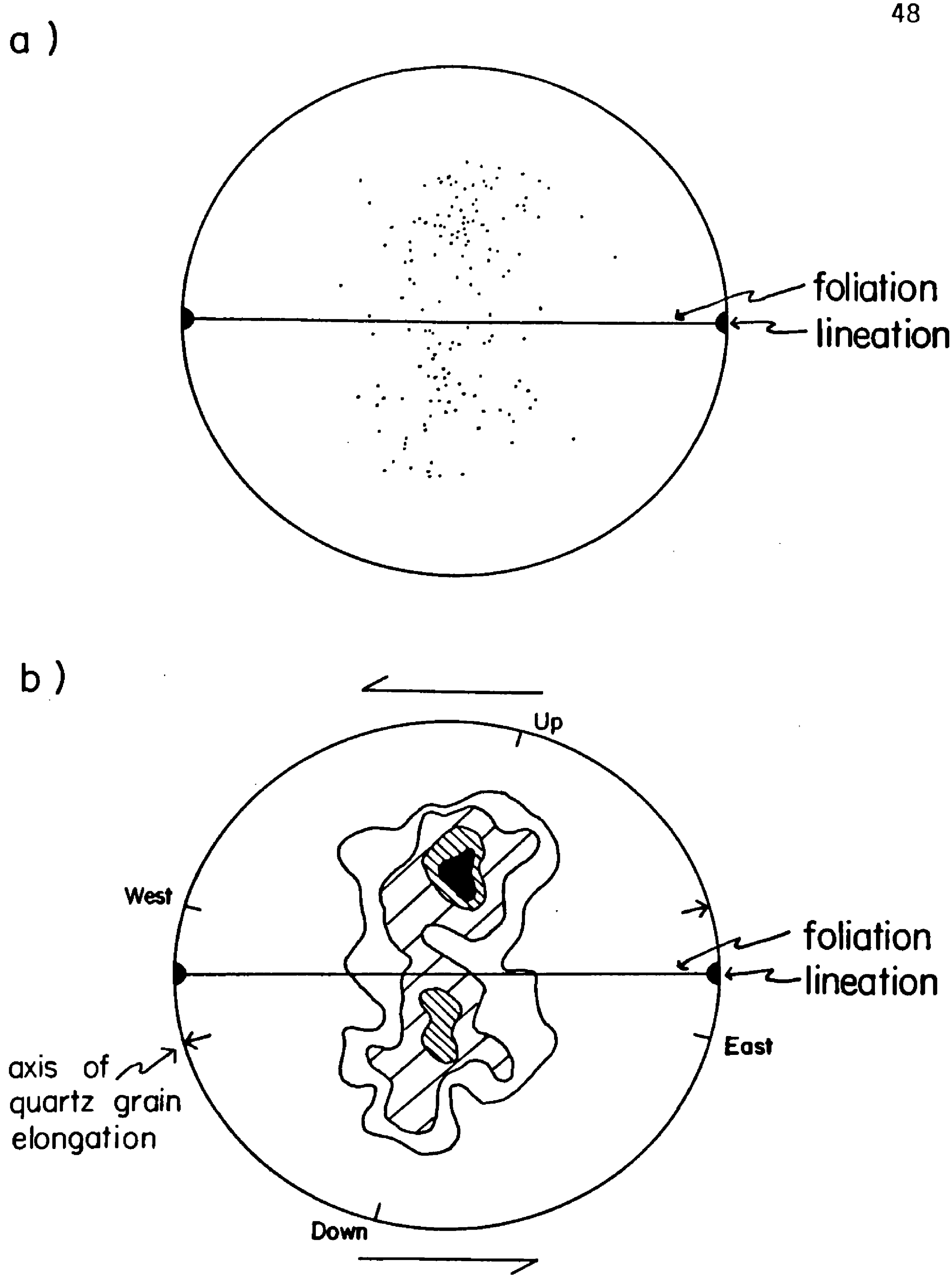


Figure 13. Equal-area projection of c-axes of 150 elongate quartz grains from sample 26, a west-dipping mylonite. Contours at 1, 3, 7 and 10 per cent (maximum 14 per cent) per 1 per cent area, deduced sense of shear and projection orientation shown in b).

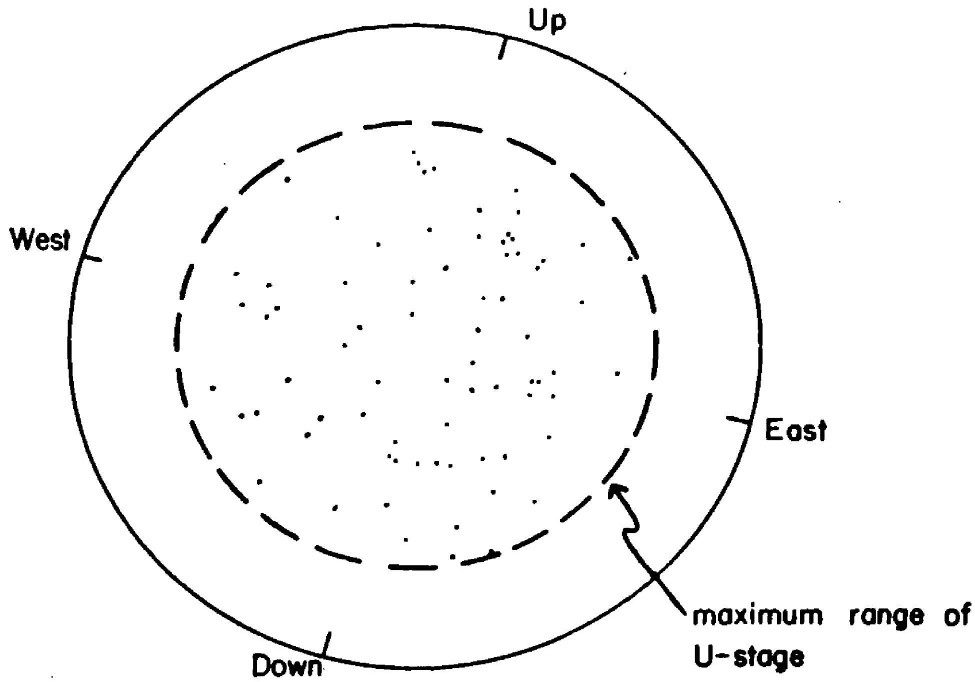


Figure 14. Equal-area projection of c-axes of 75 non-recrystallized relict quartz grains from sample 26. Maximum range of U-stage and orientation of projection shown.

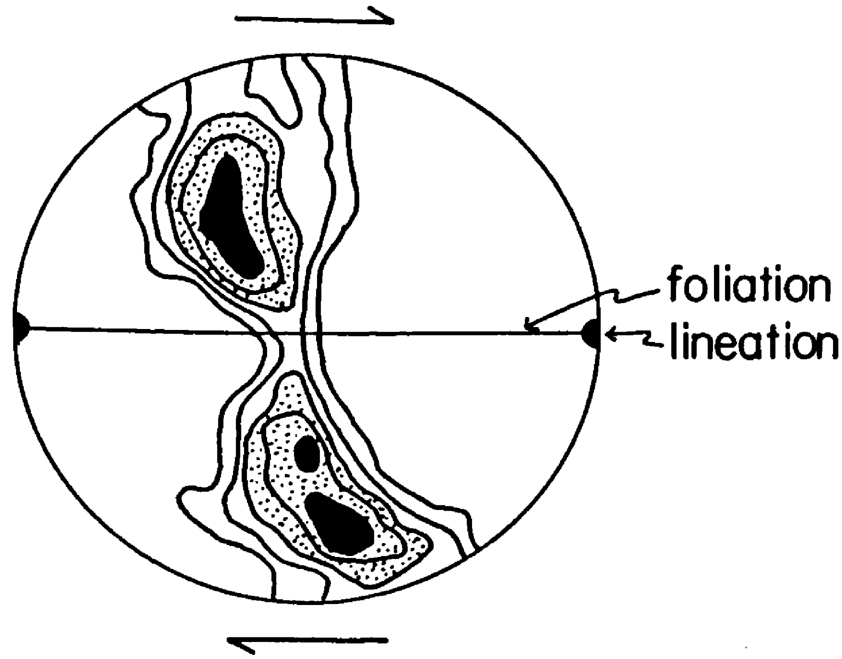


Figure 15. Sense of shear deduced from assymmetry of quartz c-axis fabric. After Lister and Williams (1979).

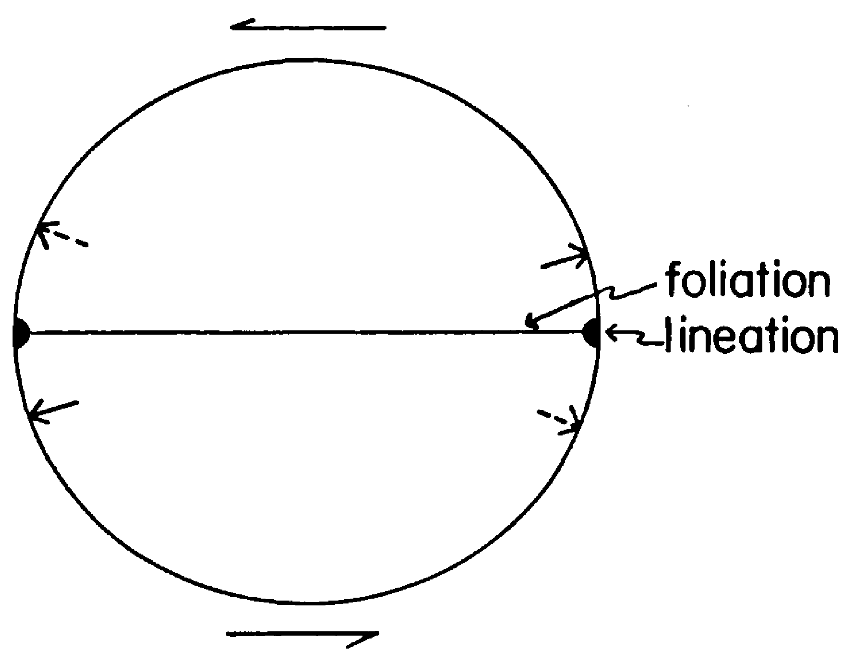


Figure 16. Equal-area projection of the axis of quartz grain elongation (solid arrows) for sample 26, a west-dipping mylonite. Sense of shear deduced from comminution tails and preferred orientations of quartz c-axes shown. According to C. Simpson (personal comm. to D. Hyndman, 1981), the axis of quartz grain elongation should be inclined in the opposite direction (dashed arrows) for the sense of shear determined.

As noted above, quartz grains in the discrete shears of the west-dipping mylonites are elongate, and the axis of elongation lies at an angle of about 15° to the mylonite foliation. It has been suggested that the direction of inclination of the axis of quartz grain elongation to the foliation indicates sense of shear as shown in Figure 16 (C. Simpson, personal comm. to D. Hyndman, 1981). In the west-dipping mylonites the sense of shear indicated by this direction of inclination is opposite from that deduced from deformed muscovite books, comminution tails and the quartz c-axis fabric. Because the quartz grains themselves have a fabric (Fig. 13) indicating a sense of shear opposite from that deduced from elongate quartz grain inclination, I suggest that the direction of inclination of axis of quartz grain elongation to foliation is an unreliable indicator of sense of shear. I can offer no rational explanation for this quartz microstructure.

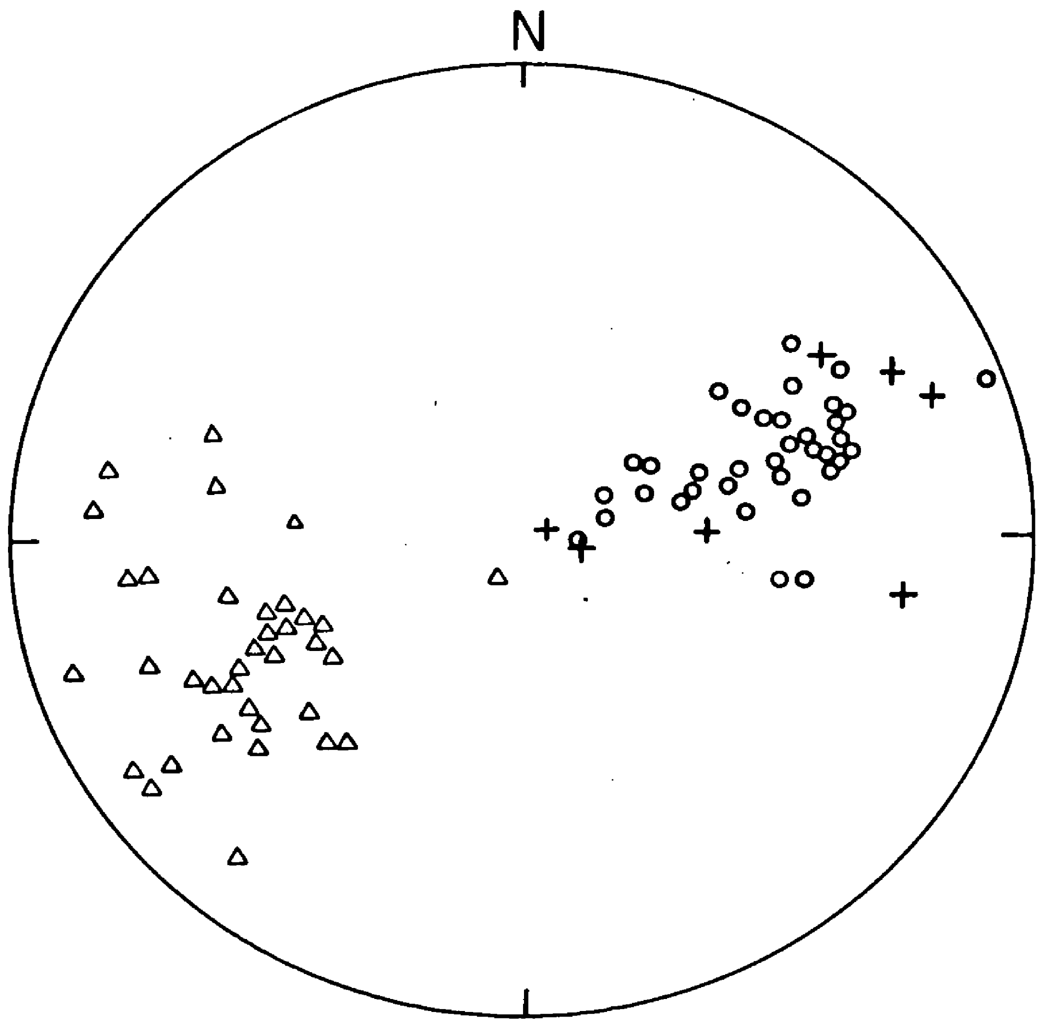
Cataclastic Deformation

Slickensided surfaces. Numerous slickensided surfaces are exposed in railroad cuts near Kootenay Landing and also near the mouth of Next Creek. Near Kootenay Landing the slickensided surfaces are exposed over an area about coincident with that of the west-dipping mylonites. These surfaces are commonly curviplanar, but slickenside striations maintain a constant trend through the curves. In one location, a west-dipping mylonite is cut off by, and appears to be drag-folded against, a slickensided surface. Drag-folding indicates normal displacement on the slickensided surface.

A stereographic projection of slickensided surfaces and slickenside lineations is shown in Figure 17. Slickensided surfaces have a variable, but generally moderate-to-steep east- to northeast-dipping attitude. Plunge of the slickenside lineations varies from moderate to steep, but it consistently trends about N70°E, parallel to the mylonite lineation. As shown in Figure 17, Nevin (1966) measured a slickenside lineation of nearly identical attitude on the west side of the Purcell Trench about 65 kilometers to the south.

Microbreccia. Microbreccia is a term used to describe a very fine-grained, massive, intensely brecciated but completely coherent rock (Higgins, 1971). Microbreccias are characteristic of faulting at crustal levels only slightly higher than those at which mylonites form (Sibson, 1977).

Microbreccia is exposed structurally underlying and possibly contiguous with the east-dipping mylonite zone at its southern end (see Fig. 2). As is the case with the east-dipping mylonites at the northern end of their exposure, both the microbreccia and the mylonite appear to be enclosed by, and have the same mineralogy as, the Kootenay Landing Granite. This evidence suggests that the microbreccia may parallel and be genetically related to the east-dipping mylonite zone. The outcrop pattern of the limited exposure of the microbreccia zone is consistent with that interpretation, but because the microbreccia lacks internal structure the orientation of the zone of microbreccia can not be ascertained. Exposure at the northern end of the east-dipping mylonite



o = slickenside lineation

Δ = pole to slickensided surface

+ = slickenside lineation of Nevin (1966)

Figure 17. Equal-area projection of 43 slickenside lineations and 36 poles to slickensided surfaces. Includes data from the deformation zone exposed near Kootenay Landing and from 65 kilometers to the south (Nevin, 1966).

zone is sufficiently good to rule out the possibility that microbreccia occupies the same structural position there. It is possible that some of the displacement on the east-dipping structure accommodated by ductile deformation at the northern end of the exposure of the zone may have been accommodated cataclastically at the southern end, conceivably as a result of laterally heterogeneous strain rate within the zone.

Deformation History

Analysis of textural relationships and structural fabrics observed in structures exposed near Kootenay Landing allows some conclusions regarding deformation history. Three stages of deformation, possibly representing two separate tectonic events can be distinguished. The stages of deformation history are summarized in Table 5.

In the east-dipping mylonites lozenge-shaped and stretched and flattened muscovite porphyroclasts are much coarser-grained than biotite. If those minerals underwent the same deformation, they normally would be expected to have about the same grain size. The difference in mica grain size indicates that muscovite crystallized or recrystallized after most, but not all, of the ductile deformation producing the east-dipping mylonites and implies that the east-dipping mylonites were produced by two separate ductile deformation events.

The possibility that two separate ductile deformation events have produced the east-dipping mylonites is supported by the fact that the quartz c-axis fabric for the east-dipping mylonite has a broad point maximum with a diffuse crossed-girdle (see Fig. 12). Lister and Price

		first tectonic event	second tectonic event	
			ductile stage	brittle stage
structural fabrics	east-dipping mylonites	obliterated	N70E lineation and broad point maximum and diffuse crossed-girdle quartz c-axes	
	west-dipping mylonites		N70E lineation and single-girdle quartz c-axes	
	slickensided surfaces			N70E lineation
rheology		ductile	ductile	brittle
stress orientation		indeterminate	subhorizontal, ENE-WSW extension	

muscovite growth

ductile-brittle transition

Table 5. Stages of deformation history determined from structures exposed near Kootenay Landing. See text for explanation.

(1978) report a somewhat similar fabric and demonstrate with computer simulations that the fabric can not be produced by a single-stage deformation history or multiple deformations constant in their kinematic framework. Those authors emphasize that a non-random population of quartz c-axis orientations prior to a deformation will affect the distribution of c-axis concentrations in the pattern produced by the deformation. As shown in Figure 14, the quartz of the Kootenay Landing Granite in which the east-dipping mylonites are developed apparently had a random orientation prior to any deformation. Thus in the east-dipping mylonites the ductile deformation occurring after the growth of muscovite porphyroclasts must have inherited a non-random quartz orientation from an earlier deformation event, presumably the ductile deformation event occurring prior to the growth of the muscovite porphyroclasts.

Lister and Price (1978) note that the fabric symmetry preserved in a structure is related to the symmetry of the final deformation, and information about the orientation of earlier deformation axes is obliterated by later deformation. Thus the structural fabrics in the east-dipping mylonites were produced by ductile deformation of the second tectonic event. Because deformation of the second tectonic event would have destroyed preexisting fabrics, I will not speculate about the symmetry of the ductile deformation of the first tectonic event.

The single-girdle quartz c-axis fabric determined for the west-dipping mylonite (see Fig. 13) indicates a deformation history constant in its kinematic framework (Lister and Price, 1978). Because east- and west-dipping mylonite lineations indicate transport in the same direction, the west-dipping mylonites probably were produced by the ductile deformation stage of the second tectonic event which produced the fabrics preserved in the east-dipping mylonites.

The east- and west-dipping mylonites approximately define a conjugate shear produced during ductile deformation of the second tectonic event. An orientation of principal stress axes will produce conjugate shears as shown diagrammatically in Figure 18. As shown in Figure 18, the acute angle of intersection of the conjugate shears near Kootenay Landing is about 65 degrees, and the blocks within the acute angle moved relatively outwards. Because the east-dipping mylonite is probably a reactivated structural weakness and the west-dipping mylonites appear to have been drag-folded at least locally against later slickensided surfaces, the orientation of the principal stresses producing the conjugate mylonitic shears exposed near Kootenay Landing can only be approximated.

The observed mylonitic lineation should lie in the $\sigma_1 \sigma_3$ plane, that containing the greatest and least principal stresses. The great circle that best fits the mylonite lineation is N70°E and vertical (see Fig. 6). The intermediate principal stress axis should be normal to this plane at N20°W, about horizontal. This is about the same as the orientation of the line of intersection of the conjugate shears N20°W, 10°S (Fig. 19), which is also the intermediate principal stress axis (see Fig. 18). Both the east- and west-dipping mylonites preserve evidence of a normal sense of displacement relative to their present orientations, and thus σ_3, the axis of least compressive stress, should

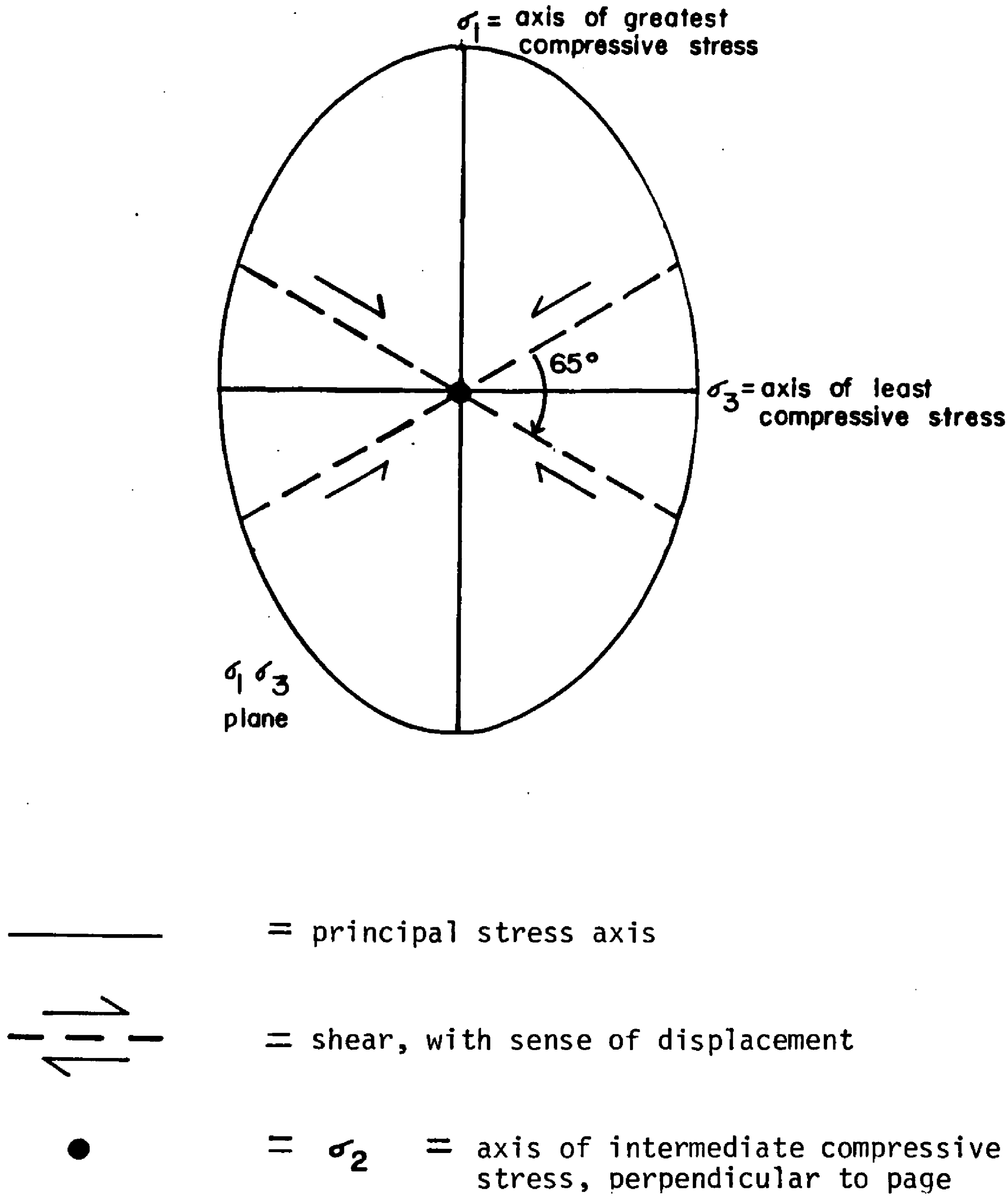
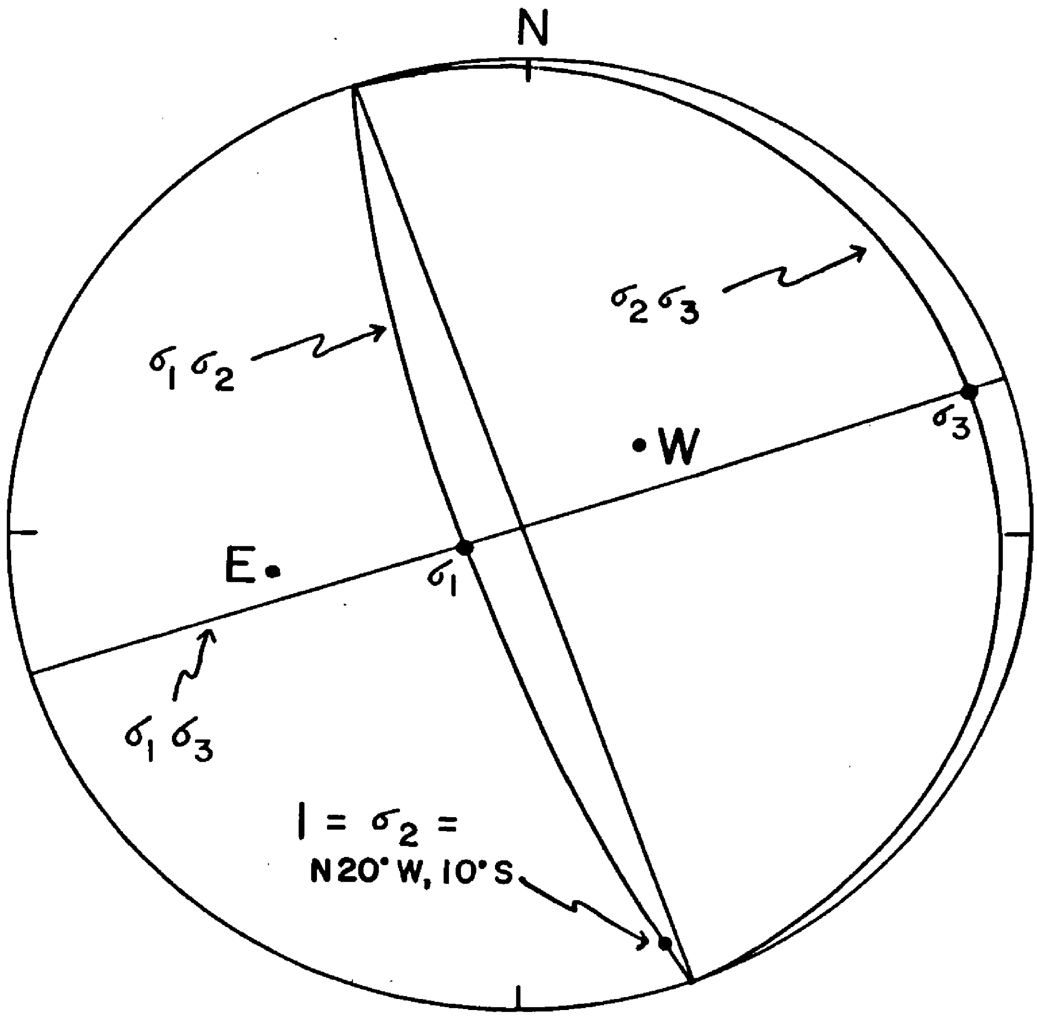


Figure 18. Relationship of conjugate shears to the sterss ellipsoid. The acute angle of intersection of the conjugate shears near Kootenay Landing is about 65 degrees.



E - pole of average east-dipping mylonite

W - pole of average west-dipping mylonite

I - line of intersection of east- and west-dipping conjugate shears

Figure 19. Equal-area projection of orientation of stress ellipsoid determined from conjugate mylonite shears.

be intersection of the σ_1 σ_3 plane and the nearly horizontal σ_2 σ_3 plane bisecting the acute angle between the conjugate shears, whereas σ_1, the axis of greatest compressive stress, should be the intersection of the σ_1 σ_3 plane and the nearly vertical σ_1 σ_2 plane bisecting the obtuse angle between the conjugate shears (see Figs. 18 and 19). The orientation of σ_1 and σ_3 must be about N70°E, 80°W and N70°E, 10°E respectively (Fig. 19). Considering the possibility of preexisting structural weaknesses and post-mylonite shear plane drag-folding, the orientation of the stresses which produced the ductile deformation of the second tectonic event can be only approximately defined as subhorizontal, ENE-WSW extension. The localized stress picture may be different from the orientation of regional stresses (eg. Moody and Hill, 1956).

The great circle that best fits the orientations of the slickenside lineations (Fig. 17) has a N70°E, vertical attitude, the same as that best fitting the lineations in both the east- and west-dipping mylonites produced by earlier ductile deformation (Fig. 6). This indicates movement in the same direction during both the later ductile and brittle stages of deformation. Although the coincident orientations of ductile and cataclastic lineations may be fortuitous, this coincidence warrants the speculation that the later ductile deformation may have been produced by stresses of the same orientation as those producing the brittle deformation and that the change in deformation character can be attributed to movement through the ductile-brittle transition during a single tectonic event. It can not be determined whether this movement through the ductile-brittle transition might have been the result of a drop in temperature or confining pressure or simply an acceleration of strain rate. Table 5 assumes that the later ductile deformation and brittle deformation were produced by the same tectonic event.

CHAPTER 4

REGIONAL TECTONIC IMPLICATIONS

Geologic observations in the study area have been presented in the chapters on Igneous Petrology and Structural Geology. Petrographic data indicates the existence of several distinctive granitic phases in the Bayonne batholith which can be distinguished, in part, by aeromagnetic anomaly patterns. Regional petrologic correlations indicate that Eocene K-Ar age determinations from the Kootenay Landing Granite and other S-type plutons in the region may be late cooling or reset dates from plutons emplaced during the mid-Cretaceous. Analysis of structures exposed in a roughly north-south-trending zone of deformation on the west side of the Purcell Trench indicates three stages of deformation, possibly representing two tectonic events. The first tectonic event involved ductile deformation. Later ductile deformation produced a conjugate mylonite shear from which a subhorizontal, ENE-WSW extension stress orientation can be determined. The later ductile deformation has produced a mylonite lineation parallel to a lineation on slickensided surfaces. This coincidence warrants the speculation that both the later ductile deformation and the brittle deformation may have been produced by stresses of the same orientation during a single tectonic event. The regional tectonic implications of these observations are explored below.

Purcell Trench Fault

As discussed in a preceding section, Miller and Engels (1975) infer a large displacement fault buried in the Purcell Trench south of the US-Canada border. Those authors suggest that the fault is a major strike-slip or thrust fault. Based on regional faulting patterns, Price and others (1981) interpreted the structure as an Eocene listric normal fault. Ewing (1980) interpreted the structure as an Eocene throughgoing strike-slip fault bounding the east side of the Selkirk metamorphic core complex.

The location of the Purcell Trench fault north of the US-Canada border is problematic. Miller and Engels (1975) suggest that the fault leaves the Purcell Trench north of the border and joins northeast-trending faults mapped by Rice (1941) east of the trench.

Near the southern half of Kootenay Lake the Purcell Trench corresponds to a postulated major fault offsetting the upper Purcell sequence and the lower Windermere supergroup (Leclair, 1982). Archibald (personal comm., 1981) postulated a fault covered by Kootenay Lake at its southern end, citing as evidence the stratigraphic offsets noted by Leclair (1982) and profound contrasts in metamorphic grade, intrusive levels and late thermal histories of intrusive rocks across the lake. The most probable location of the fault is inferred from aeromagnetic anomalies and shown in Figures 2 and 4. Archibald (personal comm., 1981) interpreted the postulated Purchell Trench fault as listric normal and this interpretation is shown in Figure 20.

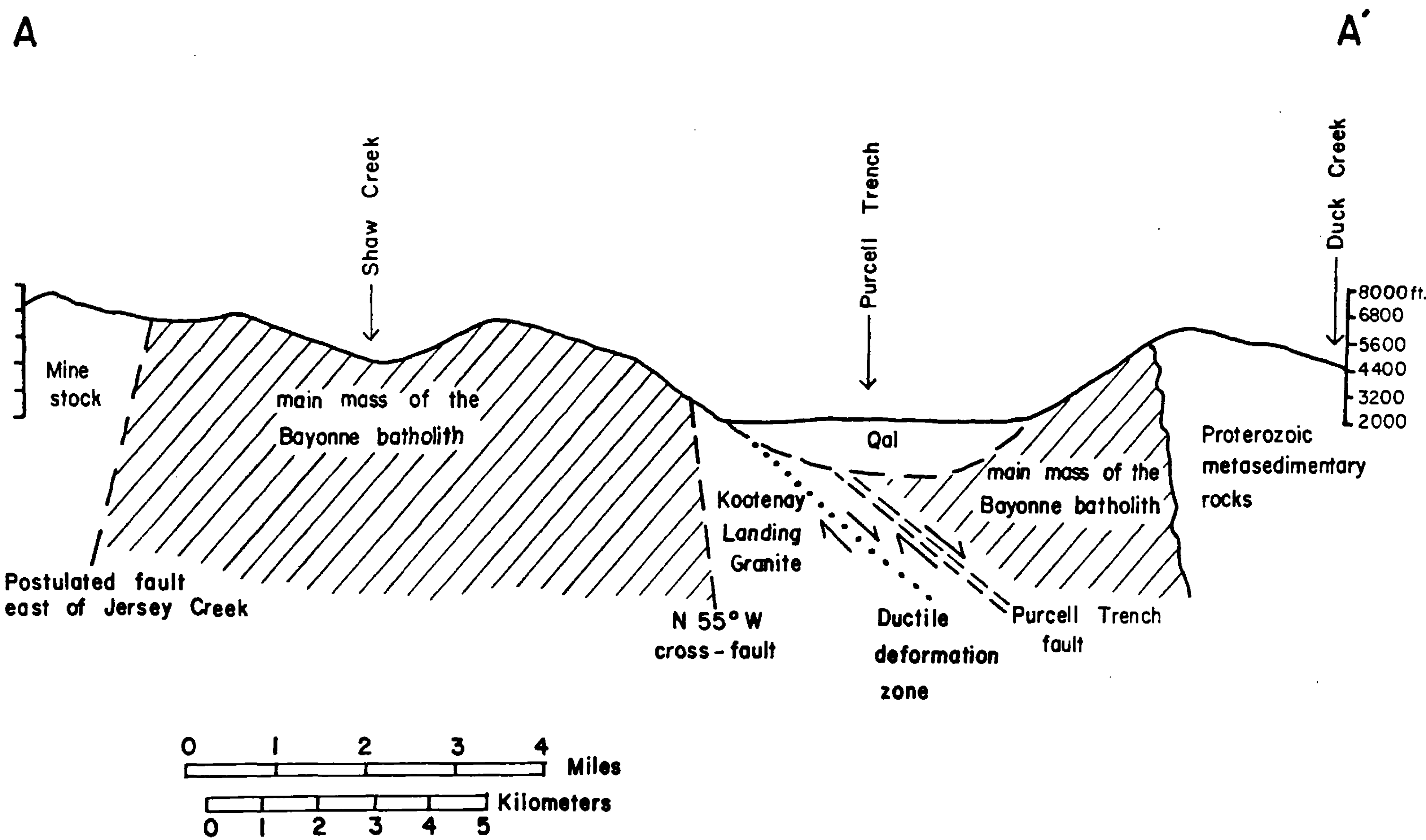


Figure 20. Geologic cross-section, no vertical exaggeration. Location of section shown in Figure 2.

The close proximity of the deformation zone exposed near Kootenay Landing to a postulated major fault buried in the Purcell Trench suggests that these structures may be related. This relationship is supported by the fact that the strike of the zone of strongly developed, east-dipping mylonites parallels the inferred strike of the postulated Purcell Trench fault. The cumulative displacement across both the ductile and brittle structures exposed near Kootenay Landing may not have been great, however, because rocks of the Kootenay Landing Granite are exposed both above and below the deformation zone and there is no evidence that the granite was intruded along the deformation zone or the possibly related nearby major fault. The apparent minor displacement across the structures exposed near Kootenay Landing suggests that if they are related to the postulated Purcell Trench fault they are only subsidiary to it.

Price (1981) interpreted the postulated Purcell Trench fault as a west-dipping structure. If the structures in the deformation zone exposed near Kootenay Landing are related to the postulated Purcell Trench fault, the fact that the exposed east-dipping mylonites are much more persistent and strongly developed than the west-dipping mylonites suggests that the Purcess Trench fault may be an east-dipping structure. The occurrence of east- to northeast-dipping curviplanar slickensided surfaces exposed near Kootenay Landing (see Fig. 17) also suggests that the major buried structure is east-dipping, as is displayed in Figure 20.

N55°W Cross-faults and Continuations of the Purcell Trench Fault

The ductile deformation zone exposed near Kootenay Landing appears to be offset by younger cross-faults at the southern end of its exposure (see page 37). This suggests that the major buried Purcell Trench fault also is cross-faulted in this vicinity. Such cross-faulting may explain the apparent westward shift of the Purcell Trench north of the US-Canada border, assuming that the structure controlling the location of the trench maintains a fairly constant north-south trend.

The aeromagnetic anomaly (see Fig. 4) from which the N55°W trend of this postulated cross-fault was inferred as part of a N55°W trending anomaly that extends for at least 21 km. This suggests that this postulated N55°W cross-fault may be a major regional structure. As shown on Figure 2, the most likely location for the Purcell Trench fault to the southwest of the postulated cross-fault is near Wynndel. This represents an apparent offset of about 10.8 km. The location of the Purcell Trench fault south from Wynndel is based primarily on aeromagnetic anomalies. In addition, limited geologic evidence north of the mouth of Summit Creek indicates that no major structural, stratigraphic or metamorphic discontinuities exist between the Bayonne batholith and the Purcell Trench and suggests that the Purcell Trench fault can not lie west of the trench in this vicinity.

If the postulated N55°W fault near Kootenay Landing continues to the northwest, a northwest-trending contact mapped by Leclair (1982) between the Kootenay Landing Granite and the Proterozoic Dutch Creek Formation near Mt. Burnett may be a segment of that fault (see Fig. 2). If major displacement has occurred on this postulated structure, Leclair's mapping constrains the direction of displacement on the fault. Because contacts between early Paleozoic and Proterozoic units appear to cross the projection of the fault without offset, the direction of displacement must be about parallel to the line of intersection between the metasedimentary units and the fault. This coincidence seems fortuitous, but an apparent facies and thickness change in the Proterozoic Monk Formation shown by Leclair (1982) approximately along the projection of the fault lends credence to this interpretation.

The Purcell Trench fault projected on its inferred N5°W trend north from Kootenay Landing should be exposed south of Sanca on the east side of Kootenay Lake (see Fig. 2). A cursory examination of highway cuts in that vicinity revealed no evidence of the structure. In contrast however, outcrops in the vicinity of Next Creek on the west side of Kootenay Lake at the north edge of the field area have numerous curviplanar slickensided surfaces similar to those exposed near Kootenay Landing. These observations suggest that the Purcell Trench fault shifts westward somewhere just south of the mouth of Next Creek (see Fig. 2). This interpretation is supported by a westward shift in the north-south trending aeromagnetic anomaly (see Fig. 4) presumably associated with the Purcell Trench fault. The attitude of the fault near Next Creek is conjectured to be parallel to that of the postulated N55°W fault to the southwest which also is associated with an inferred westward shift of the postulated Purcell Trench fault. The location of the Purcell Trench fault is unknown north from where the north-south-trending aeromagnetic anomaly completely fades out near Columbia Point.

Selkirk Metamorphic Core Complex

Geologic features characteristic of the Selkirk metamorphic core complex south of the US-Canada border are present in the vicinity of the southern end of Kootenay Lake and expand to the north the range of the terrane that can be considered the Selkirk metamorphic core complex. These geologic features include:

1) near Kootenay Landing the postulated Purcell Trench fault lies to the east of a terrane yielding Eocene K-Ar late cooling or reset dates (Archibald, personal comm., 1981) from a pluton probably emplaced during the mid-Cretaceous,
2) stratigraphic offsets (Leclair, 1982) and contrasts in metamorphic grade (Archibald, personal comm., 1981) across the trench near Kootenay Landing are consistent with a major fault separating infrastructure from suprastructure and
3) parallel slickenside lineations measured 65 kilometers apart on the west side of the Purcell Trench and indicating the localized direction of extension during cataclastic deformation suggest that the postulated faults buried in Purcell Trench near Kootenay Landing and south of the US-Canada border could be related.

A possible location of the western edge of the infrastructure in this vicinity is discussed in a following section. The northern limit of the complex is unknown beyond where the aeromagnetic anomaly presumed to be associated with the postulated Purcell Trench fault completely fades out near Columbia Point.

Complex Deformational Histories of Core Complexes

Structures exposed near Kootenay Landing record evidence of an early tectonic event characterized by ductile deformation followed by a postulated second tectonic event characterized by ductile and cataclastic deformation. The postulated second tectonic event reactivated the presently east-dipping mylonite shears and produced the west-dipping mylonites and curviplanar slickensided surfaces. A pattern of early ductile deformation followed by later cataclastic deformation is noted for other metamorphic core complexes in the central portion of the western North American Cordillera, including the eastern flanks of the Kettle Dome (Rhodes, 1980), the Monashee and Shuswap complexes (Read and Brown, 1981), and the Bitterroot Dome (Hyndman, 1980) and the Newport fault of the Selkirk complex (Miller, personal comm., 1981). This early ductile deformation may have involved detachment and sliding of suprastructure (eg. Hyndman, 1980) or distributed thrusting (eg. Cheney, 1980; Read and Brown, 1981).

As indicated by evidence for subhorizontal, roughly east-west extension and the close association of structures with a terrane yielding Eocene K-Ar dates, the postulated second tectonic event of this study correlates at least with the later cataclastic deformation event of other core complexes in northeastern Washington, northern Idaho and southeastern British Columbia. Because reactivation of structures may have obliterated earlier-formed structural fabrics, insufficient evidence is preserved in the east-dipping mylonites regarding deformation of the first tectonic event of this study to relate that deformation to deformation events elsewhere in the Selkirk metamorphic core complex or in other core complexes.

Timing of Regional Tectonic Events

The occurrence of an Eocene tectonic event in northeastern Washington, northern Idaho and southeastern British Columbia is widely accepted (Cheney, 1980; Rhodes, 1980; Ewing, 1980; Johnson, 1981; Price, 1981; Read and Brown, 1981). Rhodes (1980) and Read and Brown (1981) demonstrate that the Tertiary event is characterized by cataclastic deformation. Hence this Eocene tectonic event most closely correlates with the postulated second tectonic event of this study.

Most authors interpret the widely occurring K-Ar age determinations from the metamorphic core complexes of the central Cordillera as late cooling dates recording the time of the cataclastic deformation event of the complexes. This may not be the case for the Idaho batholith (Criss and Taylor, 1978). Because the blocks in northeastern Washington, northern Idaho and southeastern British Columbia are usually bounded by major structures that may have been active during the Eocene, the interpretation that the Eocene K-Ar dates are related to tectonism is rational. This interpretation is complicated, however, by the recognition of an intrusive event of probable Eocene age (see page 32) which suggests that some of the dates could be caused by thermal resetting.

The widespread occurrence of Eocene K-Ar dates in the region suggests that either structural blocks were rapidly uplifted through essentially stationary isotherms for Ar retention or those isotherms moved rapidly downward through stationary or slowly uplifting structural blocks. Any sudden increase in cooling efficiency should cause the isotherms for Ar retention to rapidly drop. Tectonism may increase cooling efficiency by augmenting strictly conductive cooling in the following manner. Tectonism may cause the initial fracturing of holocrystalline metamorphic and plutonic rocks, allowing cool surface water to circulate by convection through the fractured rocks and rapidly cool them through the blocking temperature for Ar retention.

The timing of the early ductile deformation event affecting the metamorphic core complexes of the central Cordillera is defined largely by circumstantial evidence. The most likely maximum age for the event is established by the age of the plutons deformed during the event. An S-type pluton lying to the west of the Hauser and Newman Lake Gneisses in the Spokane dome has a northeast-trending lineation (Miller, 1974b) inferred to have developed during the first tectonic event affecting the Selkirk metamorphic core complex. This pluton probably was emplaced at about 111 Ma (see page 27), and thus the first event occurred after 111 Ma. The occurrence of a 150 Ma pluton apparently intruding early-developed mylonites in the Monashee Complex (Read and Brown, 1981) contradicts this interpretation if the structures are correlative and the age determination and observed geologic relationships are correct. The fact that the Monashee Complex has undergone an intense probable mid-Mesozoic deformation (Hyndman, 1968; Read and Brown, 1981) raises the possibility that the structures cut by the 150 Ma pluton in the Monashee complex indeed may not be correlative with structures of the first tectonic event of this study. The most likely minimum age for the early ductile deformation event is established by analogy with the Monashee Complex, where the Goat Canyon-Halifax Creek stock with K-Ar biotite age of 107 ± 8 Ma apparently intruded mylonites developed on the eastern edge of the complex (Read and Brown, 1981).

A mid-Cretaceous age for the early ductile deformation event in northeastern Washington, northern Idaho and southeastern British Columbia is supported by K-Ar data presented in Fox and others (1977) and shown in Figure 21. An obvious clustering of Eocene dates is evident in the data, associated with the later cataclastic deformation event discussed above. A clustering of dates around 90-100 Ma is less obvious but unmistakeable. I propose that this clustering is due to the gross fracturing of suprastructure rocks at this time and their rapid cooling by circulating water, as discussed above. Many of these 90-100 Ma dates probably come from plutons emplaced much earlier. These plutons probably lost Ar during the region-wide intrusion of hot S-type magmas into upper levels of the crust at about 111 Ma (see page 27) but again began retaining Ar a short time later after fracturing and cooling during deformation of the first event.

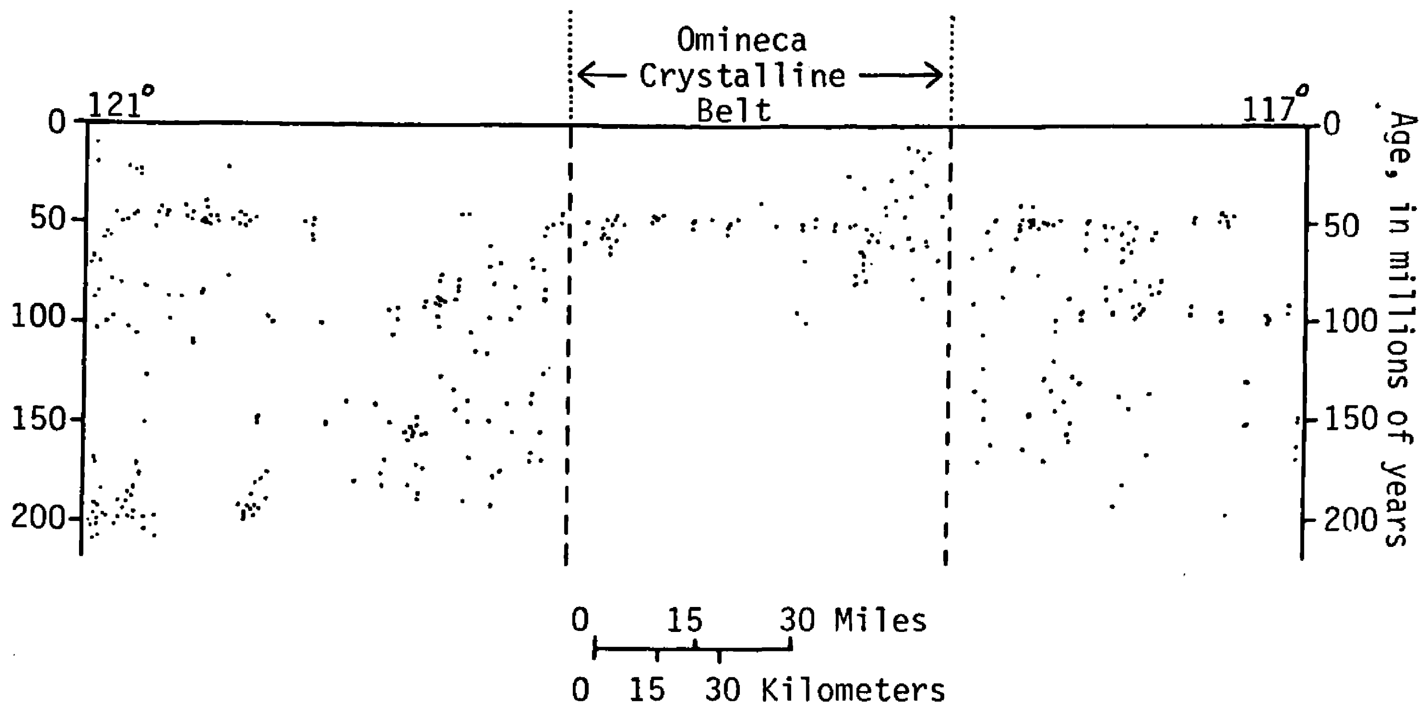


Figure 21. Mesozoic and Cenozoic age determinations within the region bounded by 117° and 121° W longitude and 48° and 51° N latitude plotted with respect to the Omineca Crystalline Belt and projected to the 49th parallel. After Fox and others (1977).

St. Mary Fault

The southwesterly projection of the St. Mary fault, a probable reactivated structure of at least Proterozoic age (Lis and Price, 1976), should cross the Purcell Trench in the vicinity of the southern end of Kootenay Lake (see Fig. 1). In the course of this study, no evidence of northeast-trending shear zones or contact offsets was found in the rocks of the Bayonne batholith to suggest that the St. Mary fault cuts the batholith. This supports the interpretation of Rice (1941) and Archibald and others (1977) that the Bayonne batholith was intruded subsequent to the final displacement on the St. Mary fault which therefore must be pre-mid-Cretaceous.

Fault Near Jersey Creek

A marked contrast in time of final retention of Ar over a short distance suggests a major fault a few kilometers west of the Purcell Trench in the vicinity of the Bayonne batholith. Plutonic rocks of the Summit stock (see Fig. 1), a probable S-type pluton, yield concordant K-Ar ages of 102 Ma from both muscovite and biotite (Archibald, personal comm., 1981). Roughly 15 kilometers away, muscovite and biotite from the S-type Kootenay Landing Granite, probably emplaced in mid-Cretaceous time, finally began retaining Ar only at 45-50 Ma. The postulated fault separating these plutons with different late thermal histories probably lies to the east of the Mine stock, because biotite from the contact aureole of that pluton yields a 160 Ma K-Ar date. As shown in Figures 2 and 20, a likely location of the fault is at the contact between the Mine stock and the main mass of the Bayonne batholith. This contact lies east of the ridge between Jersey and Shaw Creeks but has not been mapped in this study. East of Jersey Creek an aeromagnetic anomaly trending about north-south (see Fig. 4) may correspond with this contact.

Elsewhere in the region, faults bounding blocks with Eocene K-Ar plutonic mica ages trend about north-south (Price, 1981). If such is the case with the postulated fault east of Jersey Creek, the fault lies approximately on trend with the southerly extension of the Blazed Creek fault (see Fig. 1). This raises the possibility that the northeast-trending and north-south-trending segments of the Blazed Creek fault are not the same structure (cf. Rice, 1941; Glover, 1978), and further, that the north-south-trending segment of the Blazed Creek fault may be the northerly continuation of the Newport fault (Miller and Engels, 1975). If the postulated fault east of Jersey Creek is a continuation of the Newport fault, it may mark the western edge of the Selkirk metamorphic core complex infrastructure in this vicinity. Detailed mapping of metamorphic and structural features in this vicinity may resolve these questions.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Igneous Petrology

The Bayonne batholith straddles the Purcell Trench at the southern end of Kootenay Lake in southeastern British Columbia and is a composite granitic body, both in terms of composition and probable age. The Mine stock, a probable Middle Jurassic pluton (Archibald and others, 1977), forms the western portion of the batholith (Rice, 1941). My investigation found that the Mine stock itself is a composite body, consisting of a more characteristic hornblende-biotite-bearing phase (Rice, 1941) and a newly identified biotite-bearing phase. The main mass of the Bayonne batholith was probably emplaced prior to mid-Cretaceous time. This phase contains much more accessory magnetite than any other Bayonne batholith phase, making possible the location of contacts between phases on the basis of aeromagnetic anomalies (GSC maps 8475G and 8476G). This study identifies a distinctive new phase of the Bayonne batholith, here named the Kootenay Landing Granite. This phase is located on the west side of Kootenay Lake at its southern end.

The Kootenay Landing Granite is an S-type granite (Chappell and White, 1974), as indicated by the presence of muscovite, monazite and ilmenite and the absence of hornblende, epidote, sphene and magnetite. A comparison made for this study from published petrologic descriptions indicates that as an S-type granite the Kootenay Landing Granite correlates petrologically with other plutons in the region including those of the two-mica suite identified by Miller and Engels (1975) in northeastern Washington and northern Idaho and other plutons in Canada including the eastern phase of the Bugaboo, the Horsethief Creek and the Fry Creek batholiths (Reesor, 1973), the core phase of the White Creek batholith (Reesor, 1958) and possibly the Summit stock. Other phases of the Bayonne batholith and other plutons in the region are I-type granites (Chappell and White, 1974), including plutons of the hornblende-biotite suite identified by Miller and Engels (1975) and the border phases of the White Creek batholith (Reesor, 1958), among others. The distribution of S- and I-type granites in the region is shown in Figure 1.

S-type granites occur only on the convex side of the Kootenay Arc. If S-type granites are the result of partial melting of continental crust (eg. McCulloch and Chappell, 1982), the Kootenay Arc may mark the western edge of the autochthonous Precambrian continental crust of the North American craton. Based on geophysical evidence and balanced structure sections, Price (1980) reached the same conclusion for the central portion of the Kootenay Arc. The southwesterly portion of the Kootenay Arc is northeast-trending and lies along the trend of a major crustal structure identified by Kanasweich and others (1969). Because of this alignment and lacking any evidence to the contrary, the continental crust inferred to underlie this region is assumed to be an autochthonous portion of the North American craton. The geographic extent of autochthonous craton west of this region is unknown.

Evidence presented in this study suggests that three separate, distinguishable intrusive events occurred in the infrastructure of the Selkirk metamorphic core complex. Six reported intrusive relationships show I-type plutons older than S-type plutons, and one shows the opposite relationship for an I-type pluton with a fine-grained groundmass. Radiometric age determinations in the region (Reesor, 1973; Miller and Engels, 1975; Archibald, personal comm., 1981) show concordant Eocene K-Ar dates for an I-type pluton with a fine-grained groundmass, suggest a maximum mid-Cretaceous age for S-type granites indicated by one Rb-Sr whole rock and three concordant K-Ar dates and show other I-type plutons yielding commonly discordant Eocene and mid-Cretaceous K-Ar dates but also some that are much older. This evidence suggests a protracted(?) pre-mid-Cretaceous I-type intrusive event followed by a mid-Cretaceous S-type event followed by an Eocene I-type intrusive event when plutons with fine-grained groundmass were emplaced in the infrastructure of the complex. This speculation would not be warranted without the knowledge that elsewhere in the world S-type and I-type intrusive events are commonly separated temporally (eg. Chappell and White, 1974; Pankhurst, 1979; Beckinsale, 1979).

Structural Geology

A zone of ductile and cataclastic deformation has developed in rocks of the Kootenay Landing Granite at the southern end of Kootenay Lake on the west side of the Purcell Trench. Mylonites produced by ductile deformation are of two varieties, one strongly developed, generally east-dipping and restricted to a twelve meter-thick zone, and the other weakly developed, generally west-dipping and distributed over a wider area. Mylonite lineations have a consistent N70-75°E trend. Indicators of sense of shear including deformed muscovite books, sigmoidal foliation around feldspar porphyroclasts, comminution tails and preferred orientation of quartz c-axes consistently show a normal sense of displacement for both the east- and west-dipping mylonites relative to their present orientations. Slickensided surfaces in the deformation zone are commonly curviplanar and dip eastward at moderate to steep angles. Slickenside lineations consistently trend about N70°E, parallel to the mylonite lineations. Microbreccia indicative of faulting at crustal levels only slightly shallower than those where mylonites form (Sibson, 1977) outcrops at the southern end of the exposure of the deformation zone. There the microbreccia may be structurally contiguous with the narrow zone of east-dipping mylonites.

Analysis of textural relationships and structural fabrics from the deformation zone allows some conclusions regarding the deformation history of thoes structures. Three stages of deformation history, possibly representing two separate tectonic events, can be distinguished. The first tectonic event involved ductile deformation before the growth of the muscovite porphyroclasts present in the rocks. The quartz c-axis fabric from an east-dipping mylonite supports the interpretation that two separate tectonic events have affected the east-dipping mylonites. The orientation of the deformation axes for the first tectonic event can not be determined because later deformation may have obliterated earlier-formed fabrics. The second tectonic event may have involved both ductile and brittle deformation and occurred after the growth of the muscovite porphyroclasts present in the rocks. East- and west-dipping mylonites define a conjugate shear determined to have been produced by the ductile deformation stage of the second tectonic event. The acute angle of intersection of the conjugate shears is about 65 degrees and the blocks within the acute angle moved relatively outwards. A subhorizontal, ENE-WSW extension stress orientation is indicated by this conjugate shear. The coincident orientations of cataclastic lineations and mylonite lineations produced by ductile deformation of the second tectonic event warrants the speculation that both deformations may have been produced by stresses of the same orientation and that the change in deformation character can be attributed to movement through the ductile-brittle transition during a single tectonic event.

Regional Tectonic Implications

Stratigraphic offsets (Leclair, 1982) and contrasts in metamorphic grade, intrusive levels and late thermal histories of intrusive rocks across the southern end of Kootenay Lake suggest that a major listric normal fault is buried in the Purcell Trench in that vicinity (Archibald, personal comm., 1981). The close proximity of the deformation zone exposed near Kootenay Landing to the postulated Purcell Trench fault suggests that these structures may be related. If so, the exposed structures may only be subsidiary to the postulated fault.

The postulated Purcell Trench fault appears to be offset by younger N55°W cross-faults, the locations of which are inferred partially from aeromagnetic anomalies. This younger cross-faulting may explain the westward shift of the Purcell Trench north of the US-Canada border, assuming that the fault controlling the location of the Trench maintains a nearly north-south trend.

Geologic features characteristic of the Selkirk metamorphic core complex are present in the vicinity of the southern end of Kootenay Lake. These geologic features include a metamorphic-grade contrast across a postulated Purcell Trench fault and the association of a terrane yielding Eocene K-Ar dates to the west of it. In addition, parallel slickenside lineations measured near Kootenay Landing and 65 kilometers to the south on the west side of the Purcell Trench suggest that faulting in those localities could be related. This evidence expands to the north of the range of the terrane that can be considered the Selkirk metamorphic core complex.

A pattern of early ductile deformation followed by alter cataclastic deformation is noted for other metamorphic core complexes in the central Cordillera (eg. Hyndman, 1980; Rhodes, 180; Read and Brown, 1981; Miller, personal comm., 1981). I speculate that the later ductile and cataclastic stages of deformation determined near the southern end of Kootenay Lake occurred during the same tectonic event. This postulated tectonic event correlates at least with the later cataclastic deformation event of other core complexes. The first tectonic event of this study can not be related to deformation events elsewhere in the region because the reactivation of structures during the second tectonic event may have obliterated earlier-formed fabrics.

The age of the later cataclastic deformation event of the Selkirk metamorphic core complex and the postulated second tectonic event of this study is established by the generally discordant Eocene K-Ar dates from the infrastructure of the complex. The relationship of tectonism to Ar retention is rationalized in this study by suggesting that tectonism during the Eocene caused the initial gross fracturing of the rocks in the complex which permitted cool surface water to efficiently circulate through the rocks and rapidly cool them through the temperature required for Ar retention. Using similar rationale, the widespread occurrence of mid-Cretaceous K-Ar dates in the suprastructure of the Selkirk metamorphic core complex and elsewhere in the region (Reesor, 1973; Miller and Engels, 1975; Fox and others, 1977) may establish the age of the early ductile deformation event of this and other central Cordilleran complexes. A minimum mid-Cretaceous age for the mylonites on the eastern edge of the Monashee complex (Read and Brown, 1981) is consistent with this determination. The early ductile deformation of the Selkirk metamorphic core complex affected S-type plutons, and if, as suggested in this study, all S-type plutons in the region were emplaced in mid-Cretaceous time, the early ductile deformation of the complex must have shortly followed the S-type intrusive event.

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